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SCHEDULE-ASSESSMENT METHODS FOR SURFACE-LAUNCHED INTERCEPTORS

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August 1995

Prepared for
Ballistic Missile Defense Organization

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PREFACE

This paper was prepared by the Institute for Defense Analyses (IDA) for the Ballistic Missile Defense Organization under a task entitled "Methods To Assess Schedules for the Strategic Defense System." The objective of the task is to develop analytical tools for assessing proposed schedules for missile defense elements. This paper fulfills this objective for surface-based elements.

This work was reviewed within IDA by Philip M. Lurie, William J. E. Shafer, and Maile E. Smith.

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I. INTRODUCTION

A. BACKGROUND

Representatives of the Ballistic Missile Defense Organization (BMDO) are responsible for reviewing acquisition programs for surface-based interceptor systems that constitute proposed theater missile defense (TMD) architectures. Parts of this process involve the review of proposed acquisition schedules. BMDO needs tools for use when engaged in such reviews. The research documented in this paper was initiated to provide methods for assessing the reasonableness of proposed acquisition schedules for surface-based interceptor elements of proposed TMD architectures. Such methods should reproduce schedules typical of analogous historic systems while accounting for schedule variations associated with differing technical or program characteristics.

B. APPROACH

This work follows on three previous IDA studies of tactical aircraft, air-launched missile, and unmanned spacecraft acquisition schedules [1, 2, and 3]. The approach used here in many ways parallels that used for those studies. Our approach was to:

- Collect historical schedule and technical data on surface-launched interceptor programs. Because all tactical missile programs have common elements, we combined these data with updated data from [2].
- Present historical missile acquisition program schedules and related data in consistent formats for use in data analyses and for comparison with proposed acquisition programs.
- Analyze schedule intervals in the data, derive time-estimating relationships (TERs), and integrate the TERs into a schedule-assessment tool that spans the period from the start of prototype efforts through early production.

Research in the area of interceptor missile schedules beyond the previous IDA study has been minimal. More general research in aerospace system schedules is reviewed in [1], while research specific to space systems is reviewed in [3].

The examination of historical data is the appropriate starting point for the development of a schedule-assessment tool. We collected schedule data on 22 missile programs. Also of relevance were the program and technical parameters to which the length of schedule intervals may be related. The programs are listed in Table I-1, which also contains a summary of program attributes. Included in our sample are missile programs that involved substantial developments from the mid-1960s to the 1990s. Our sample contains eight surface-launched interceptors, seven air-launched interceptors and seven air-launched surface-attack missiles.

Table I-1. Programs in the Sample

Program	Year of First Guided Launch	Development Contractor	Primary Mission
IHAWK	1967	Raytheon	Surface-Launched Interceptor
PATRIOT A	1975	Raytheon	Surface-Launched Interceptor
PATRIOT MM	1992	Raytheon	Surface-Launched Interceptor
Stinger	1973	General Dynamics	Surface-Launched Interceptor
SM-2	1974	General Dynamics	Surface-Launched Interceptor
Sprint	1965	Martin Marietta	Surface-Launched Interceptor
Spartan	1968	McDonnell Douglas	Surface-Launched Interceptor
ERINT	1993	LTV	Surface-Launched Interceptor
Sparrow F	1968	Raytheon	Air-Launched Interceptor
Sparrow M	1980	Raytheon	Air-Launched Interceptor
Sidewinder L	1973	Raytheon	Air-Launched Interceptor
Sidewinder M	1978	Raytheon	Air-Launched Interceptor
Phoenix A	1966	Hughes	Air-Launched Interceptor
Phoenix C	1980	Hughes	Air-Launched Interceptor
AMRAAM	1985	Hughes	Air-Launched Interceptor
Maverick E.O.	1969	Hughes	Air-Launched Attack
Maverick IIR	1980	Hughes	Air-Launched Attack
SRAM A	1969	Boeing	Air-Launched Attack
Harpoon	1974	McDonnell Douglas	Air-Launched Attack
ALCM	1979	Boeing	Air-Launched Attack
HARM	1979	Texas Instruments	Air-Launched Attack
Hellfire	1978	Martin Marietta	Air-Launched Attack

In the previous IDA studies, the emphasis was on EMD. Because most proposed BMDO interceptor programs have extensive pre-engineering and manufacturing development (EMD) efforts planned, we chose to expand the analyses to provide more emphasis on pre-EMD prototype programs. We define a pre-EMD prototype program as a development effort prior to EMD that includes the flight testing of missile hardware.

In order to analyze the data, we decomposed the development program schedules into four periods for which estimating relationships could be found. (We refer to these periods as "intervals" even though they are not necessarily mutually exclusive; that is, some intervals overlap.) The primary technique in defining and testing these relationships was least squares regression analysis. For some relationships we also employed a frontier function approach. The data used in the analyses are contained in Chapter II.

The four program intervals we analyzed were: (1) time to first guided launch as measured from development start to first guided launch, (2) length of the development flight test program as measured from the first guided launch to the end of initial operational testing, (3) early production time as measured from long-lead and full-funding release for the initial production lots to the first production deliveries for those lots, and (4) program length from first launch as measured by the time from first guided launch to first production delivery. Time to first guided launch and flight test intervals are relevant to both EMD and pre-EMD programs, while the production intervals are relevant only to EMD programs. Figure I-1 shows the relationship of these four intervals for a notional interceptor program.

An issue that arose when determining the intervals to be analyzed was: what milestone should mark the end of development? Because definitions of initial operational capability (IOC) differ among programs, and because some inconsistencies in the relationship between IOC dates and other program milestones were unexplained, we chose not to use IOC to mark development completion. Another possibility for development end was the completion date of the guided-launch test program through initial operational testing. If we considered this the completion of development, an estimate of total development length could be made by simply adding the estimated length for time to first guided launch to that for the flight test program. However, we were searching for a milestone related to the availability of missiles for operational inventories. Because production start, and hence the delivery of production missiles, is not tied to a test milestone common to all programs, test program end was not a consistent indicator of the availability of operational missiles. Production milestones are related to the test program through the overlap of the test program with initial production activity. The degree of overlap (which we refer to as "concurrency") can vary widely between programs and, within limits, is determined by policy makers.

In the earlier study on tactical aircraft schedules, we used the delivery date of a quantity of aircraft associated with squadron size, 24, as the development end date. Unfortunately, the inventory requirements and the production rates associated with different types of missiles vary widely, so using a milestone associated with a fixed number of production deliveries would lead to inconsistencies across programs.

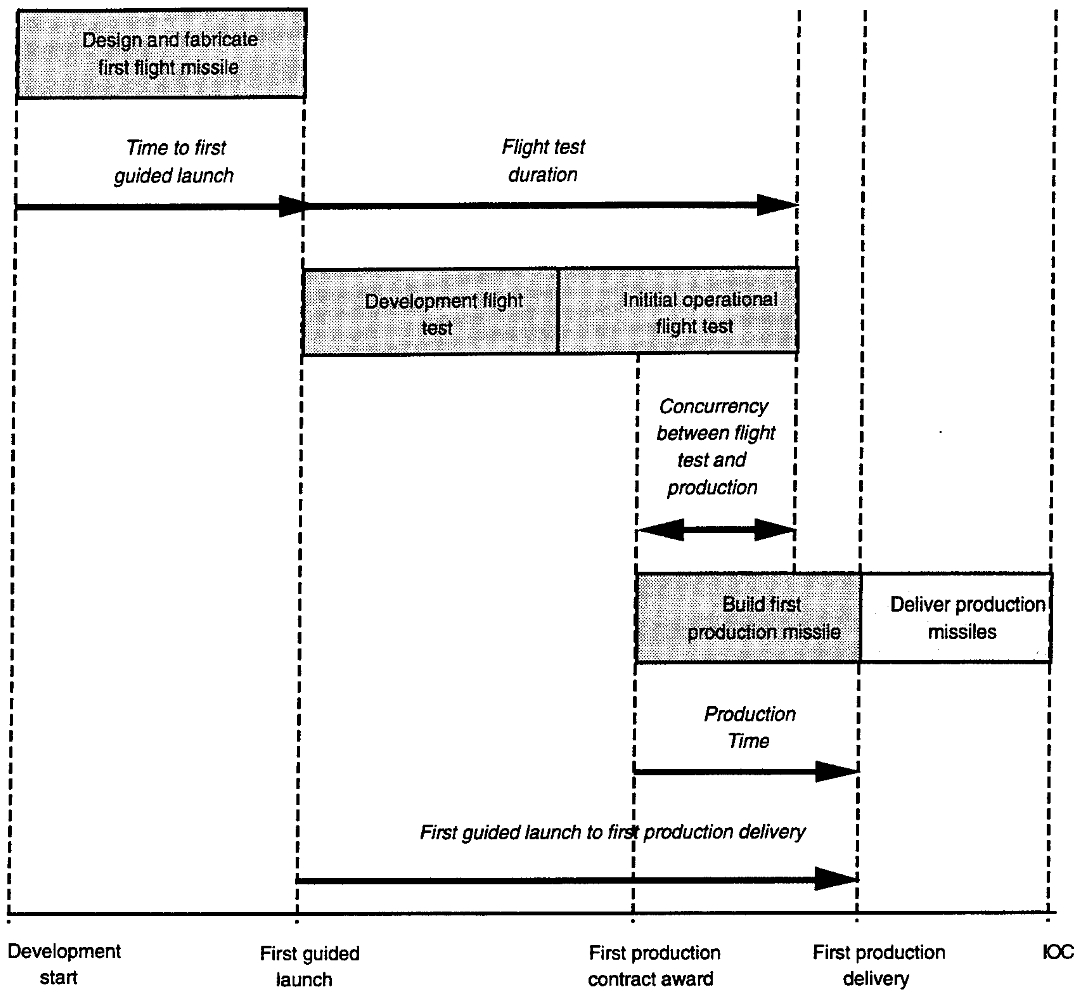

Figure I-1. Notional Interceptor Development Schedule

For those reasons, we decided to use the delivery date of the first production missile to mark the end of development. Given this definition of development end, the estimating relationships derived from the analysis of schedule interval data can be used to estimate overall development program length in two ways. Both ways use the same TER to estimate time to first guided launch. The preferred way of arriving at the time from first guided launch to first production delivery is to separately estimate flight test program parameters and the production time for the first production lot, and then combine these two estimates (i.e., combine the estimates for intervals 2 and 3) using an explicit measure of concurrency. We also estimated a single TER for program length from first guided launch (interval 4) as an alternative method and an aggregate check on the first method.

In applying statistical analyses, we treated schedule intervals (measured in months) as dependent variables and regressed them against independent variables that were thought to influence these intervals. The adequacy of these regression models was tested using standard measures of statistical significance and model fit. Models whose parameter estimates carried intuitively incorrect signs (for example, if the model indicated decreasing interval lengths with increasing missile weight) were rejected. This work is documented in Chapter III.

The one interval for which length was not directly estimated was the span of the development flight test program. Here the dependent variable was the average months between test launches by test program phase. Given this value and information about the number and employment of test missiles, the length of the flight test program could be determined. In addition to estimating months/launch, we also developed an equation to be used in estimating the number of test launches.

Once we developed satisfactory estimating relationships for the length of the four intervals, we incorporated the relationships into an internally consistent schedule assessment methodology. This methodology is demonstrated in an example application contained in Chapter IV.

II. DATA COLLECTION AND PRESENTATION

A. DATA COLLECTION

We collected detailed data on 22 missile programs. The criteria for selecting a program for inclusion were the newness of the program, its importance in historical perspective, and the expected availability of data. Most interceptor missile programs involving major developments that occurred from the late 1960s to the early 1990s are included in the database. The programs include both air- and surface-launched interceptors. Although the focus of the study was on interceptor missiles, we included seven air-launched attack missile programs in our database. The attack missile program schedules tend to be influenced by the same things (called "drivers") as the interceptor programs. The missiles hardware also share many attributes, with precision guidance systems evident in both attack and interceptor missiles.

In the data collection effort, emphasis was placed upon the EMD phase of the acquisition cycle and pre-EMD prototype developments. Schedule intervals in the concept exploration phase and the demonstration and validation phase prior to EMD are often highly dependent upon political factors and were therefore not emphasized in our data collection or analyses. Pre-EMD prototype intervals were an exception, as they have exhibited consistent patterns across programs. Some emphasis was placed on collecting production data, particularly data relevant to the initial production build-up.

Ambiguities often arise when defining program phases with which program milestones are associated. The Air Force and Army programs tend to follow the classic acquisition pattern with clear delineation between the demonstration and validation/prototype phase (Milestone I to Milestone II), the EMD phase (Milestone II to development end), and initial production. In Navy programs there is often not a clear break between what we call the pre-EMD and the EMD phase. Also in Navy programs, the delineation between EMD and production is often unclear. Pilot production contracts are often developmental in nature, providing test missiles and other support for the latter part of the development program.

Data characterizing development flight test are important. The length of the flight test program is perhaps the single most important determinate of overall development program length. Flight-test duration is determined by the number of test missiles launched and the rate at which test launches are accomplished. The most central aspect of a missile's flight testing is the guided-launch program. This is where we concentrated our data collection and analyses.

We collected data on missile physical and performance characteristics to which schedule intervals may be related. We depended on unclassified sources of information wherever possible.

Sources of the data included, the military services, prime contractors, third parties (studies and databases at IDA, RAND, etc.), and the open literature. Schedule and missile characteristic data were obtained from Selected Acquisition Reports (SARs) and numerous government and secondary data sources [References 4 through 54]. A RAND schedule interval study [4] was an important source of planning phase (pre-EMD) data. An important source of data for air-launched missile data was [5]. Data requests were sent to the services asking for detailed milestone, testing, and production data. Where the responses were lacking, we referred to secondary sources for additional data. Prominent among service sources were the Naval Air Warfare Center, Weapons Division (NAWC-WD), China Lake, California, and the U.S Army Missile Command, Redstone Arsenal, Alabama.

This chapter presents summary data on program and missile characteristics, development program schedules, flight-test programs, and early production lots. Appendix A presents more detailed schedule data, Appendix B provides detailed time-series data for selected flight-test programs, and Appendix C provides program descriptions that further document the data and put into context variations in program schedules and flight-test parameters. In the program descriptions, we graphically present the flight-test data provided in Appendix B.

B. PROGRAM AND MISSILE CHARACTERISTICS

Table II-1 presents information characterizing the eight surface-launched interceptor programs in our sample and Table II-2 characterizes the missiles associated with them. Tables II-3 through II-6 present corresponding information for the seven air-launched interceptor and seven air-launched attack missile programs and missiles. In each case, technical characteristics that might have an effect on schedule intervals are presented.

Table II-1. Characteristics of Surface-Launched Interceptor Missile Programs

Program Characteristics	MIM-23B Improved HAWK	RIM-66C/67B SM-2	MIM-104A PATRIOT	PATRIOT MM	FIM-92A Stinger	Sprint	Spartan	ERINT-1
Military Service	Army	Navy	Army	Army	Army	Army	Army	Army
Prime Contractor	Raytheon	General Dynamics	Raytheon	Raytheon	General Dynamics	Martin Marietta	McDonnell Douglas	Vought
Prototype	No	Yes	Yes	Yes	No	No	Yes	Yes
Modification	Yes	Yes	No	Yes	No	No	No	No
Pre-EMD Missiles	N/A	4	8	6	N/A	N/A	N/A	8
Pre-EMD Guided Launches	N/A	2	—	4	N/A	N/A	N/A	4
EMD Missiles	EMD: 55 IP: 41 FY69: 100	EMD: 50	EMD: 126	N/A	EMD: 179	—	—	N/A
	Total: 196	Total: 50	Total: 126	N/A	Total: 179	—	—	N/A
EMD Guided Launches	R&D: 25 ET: 16 CORE: 10 PD: 17 IP: 23 IOTE: 8	DT: 14 OT&E: 10 DT III: 10 OT III: 7 HAST: 2	Phase I: 14 Phase II: 8 Phase III ET: 27 Phase III OT: 9 Phase III DT: 4	N/A	GTV: 16 Design: 18 PQ: 32 PQ/OT II: 46 PP: 18	DT: 42 OT: 34	DT: 15 OT: 20	N/A
	Total: 99	Total: 43	Total: 62	N/A	Total: 130	Total: 76	Total: 35	N/A

Notes: N/A means not applicable. Dashes (—) mean data were not available.

Table II-2. Characteristics of Surface-Launched Interceptor Missiles

Missile Characteristics	MIM-23B Improved Hawk	RIM-66C/67B SM-2 Medium/Extended	MIM-104A PATRIOT	PATRIOT MM	FIM-92AI Stinger	Sprint	Spartan	ERINT-1
Principal Targets	Supersonic aircraft	Bombers/fighters	Supersonic aircraft	Tactical ballistic missiles	Fixed-wing aircraft/ helicopters	Strategic ballistic missiles	Strategic ballistic missiles	Tactical ballistic missiles
Terminal Guidance Type	Semi-active radar	Semi-active radar	Semi-active radar	Active radar	Infrared	Command	Command	Active radar
Length (ft.)	198	186/314.4	209	209	58	322.8	662.4	188
Diameter (in.)	14.2	13.5/18	16	16	2.75	52.8	43.1	15
Total Weight (lbs.)	1,407.2	1,558/3,320	2,200		20.85	7,600	33,500	1,214
Guidance Weight (lbs.)	144.6	97.8	116	150[a]	3.7	76.16	90	56.6
Guidance Volume (in.^{3})	—	—	1,785	—	28	—	—	1,434
Guidance Input Power (watts)	—	—	720	—	60	—	—	2,686
Guidance Power Density (watts/in.^{3})	—	—	.40	—	2.18	—	—	1.87
Range (nmi)	22	30/70	86	—[b]	1.6	32	400	—[b]
Maximum Velocity (ft./sec.)	2789	—	3,906	—[b]	2,200	8,949	8,887	—[b]
Total Impulse (lbs. × sec.)	142,328	—	274,000	—[b]	2,320	Stage 1, 965,420 Stage 2, 261,850	Stage 1, 2,411,600 Stage 2, 3,108,000	—[b]

Notes: N/A means not applicable. Dashes (—) mean data were not available, unless otherwise noted.

a Estimate based on weight change of total missile from PATRIOT A.

b Classified.

Table II-3. Characteristics of Air-Launched Interceptor Missile Programs

Program Characteristics	AIM-7F Sparrow	AIM-7M Sparrow	AIM-9L Sidewinder	AIM-9M Sidewinder	AIM-54A Phoenix	AIM-54C Phoenix	AIM-120 AMRAAM
Military Service	Navy	Navy	Navy	Navy	Navy	Navy	Air Force
Prime Contractor	Raytheon	Raytheon	Raytheon	Raytheon	Hughes	Hughes	Hughes
Prototype	No	Yes	Yes	No	No	No	Yes
Modification	Yes	Yes	Yes	Yes	No	Yes	No
Prototype Missiles	N/A	5/5	14	N/A	N/A	N/A	16/16
Prototype Launches	N/A	2/3	11	N/A	N/A	N/A	3/5
Development Missiles	EMD: 34 FY 68: 65 FY 71: 29 FY 72: 100	EMD: 44	EMD: 126	EMD: 139	EMD: 37 TP/VE: 26 SAT/VE: 31 FY 71: 69	EMD: 15 Pilot Prod: 30	EMD: 122
	Total: 228	Total: 44	Total: 126	Total: 139	Total: 163	Total: 45	Total: 122
Development Launches	CDT: 7 NTE: 42 OPEVAL I: 25 OPEVAL II: 25	CTE:13 JTE: 22 —	CTE: 10 JTE: 20 IOT&E/ OPEVAL: 30	CTE: 10 —	CDT: 26 TP/VE: 27 NTE: 11 OPEVAL: 24	CDT: 10 NTE: 6 OPEVAL: 15	DT&E/IOT&E: 91
	Total: 99	Total: not known	Total: 60	Total: not known	Total: 88	Total: 31	Total: 91
Launch Platforms Used During EMD	F-4B F-4J F-4E	—	F-4J F-4E F-14A	—	F-111B F-14A	F-14A	F-16C F-15C F-14A

Notes: N/A means not applicable. Dashes (—) mean data were not available.

Table II-4. Characteristics of Air-Launched Interceptor Missiles

Missile Characteristics	AIM-7F Sparrow	AIM-7M Sparrow	AIM-9L Sidewinder	AIM-9M Sidewinder	AIM-54A Phoenix	AIM-54C Phoenix	AIM-120A AMRAAM
Principal Targets	Fighters, bombers	Fighters, bombers	Fighters	Fighters	Bombers, cruise missiles	Bombers, cruise missiles	Fighters, bombers
Guidance Type	Semi-active radar	Semi-active radar	Passive infrared	Passive infrared	Active radar (semi-active midcourse)	Active radar (semi-active midcourse)	Active radar (command midcourse)
Length (ft.)	12	12	9.5	9.5	13	13	12
Diameter (in.)	8	8	5.0	5.0	15	15	7.1
Total Weight (lbs.)	510	510	190	190	985	1,000	342
Guidance Weight (lbs.)	57.2	61.6	5.2	5.2	166.5	179	89.0
Guidance Volume (in.^{3})	1,347	—	105	—	3,861	—	2,000
Guidance Input Power (watts)	225	—	30	—	1,600	—	2,000
Guidance Power Density (watts/in.^{3})	.17	—	.28	—	.41	—	1.00
Range (nmi)	24.0	24.0	2.0	2.0	72.5	80.0	40.0
Maximum Velocity (ft./sec.)	2421	2421	2421	1937	5990	5573	4459
Total Impulse (lb. × sec.)	36,073	31,000	13,912	13,912	97,120	97,120	—[a]

Note: Dashes (—) mean data were not available, unless otherwise noted.
[a] Classified.

Table II-5. Characteristics of Air-Launched Attack Missile Programs

Program Characteristics	AGM-65A Maverick EO	AGM-65D Maverick IIR	AGM-69A SRAM	AGM-84A Harpoon	AGM-86B ALCM	AGM-88A HARM	AGM-114 Hellfire
Military Service	Air Force	Air Force	Air Force	Navy	Air Force	Navy	Army
Prime Contractor	Hughes	Hughes	Boeing	MDAC	Boeing	TI	Rockwell
Prototype	No	Yes	No	Yes	Yes	Yes	Yes
Modification	No	Yes	No	No	No	No	No
Prototype Missiles	N/A	8	N/A	12	7	16	14
Prototype Launches	N/A	4	N/A	9	6	9	–
Development Missiles	EMD: 91	EMD: 33	—	WSD: 40 Pilot Prod: 150	EMD: 24	Phase II: 27 Phase III: 45	EMD: 215
	Total: 91	Total: 33	—	Total: 190	Total: 24	Total: 72	Total: 215
Development Launches	Cat I: 15 Cat II: 37	DT&E: 14 IOT&E: 12	Cat I & II: 38	CTE/NTE: 33 OPEVAL: 33	DT&E: 10 Follow-on DT&E: 11	CTE: 18 NTE/OT&E/ OPEVAL: 40	EMD: 169
	Total: 52	Total: 26	Total: 38	Total: 66	Total: 21	Total: 58	Total: 169
Launch Platforms Types Used During EMD	F-4D F-4EJ A-7	F-4D F-4E A-10A F-16A	B-52 FB-111	P-3C DE 1052 SSN-637 DLG/CAN	B-52	A-7C A-7E F-4G A-6E	AH-64

Notes: N/A mean not applicable. Dashes (—) mean data were not available.

Table II-6. Characteristics of Air-Launched Attack Missiles

Missile Characteristics	AGM-65A Maverick EO	AGM-65D Maverick IIR	AGM-69A SRAM	AGM-84A Harpoon	AGM-86B ALCM	AGM-88A HARM	AGM-114A Hellfire
Primary Targets	Armored vehicles	Armored vehicles	Deep air defense, fixed strategic	Surface ships	Fixed strategic	Ground radar	Armored vehicles
Guidance Type	Television	Imaging infrared	Inertial	Active radar (inertial midcourse)	Inertial with updates	Passive radar	Semi-active laser
Length (ft.)	8.2	8.2	14.0	12.5	20.8	13.6	5.4
Diameter (in.)	12.0	12.0	17.7	13.5	27.3	10.0	7.0
Total Weight (lbs.)	462.0	484.5	2,210	1,168	3,144	807	99.9
Guidance Weight (lbs.)	88.3	110.0	177	83	67	75	12.0
Guidance Volume (in.^{3})	—	—	2,088	2,122	2,100	1,350	450
Guidance Input Power (watts)	—	—	346	784	290	146	172
Guidance Power Density (watts/in.^{3})	—	—	.17	.57	.11	.11	.38
Range (nmi.)	13	13	105	60	1,500	40	6
Maximum Velocity (ft./sec.)	908	1,115	7,150	871	678	1,937	1,800
Total Impulse (lbs. × sec.)	5,426	5,426	251,392	N/A	N/A	—	135.40

Note: N/A means not applicable. Dashes (—) mean data were not available.

The 22 programs represent a rich variety in terms of both program and missile attributes. Eight different prime contractors are represented. Data on nine pre-EMD prototype programs are included. Ten of the 22 programs were modifications of previously developed missiles. Missile physical and performance characteristics vary widely and a variety of guidance types are represented.

We placed particular emphasis on collecting guidance system characteristics. Our hypothesis was that the terminal guidance system, generally the highest value item and most technologically difficult development item, would pace overall missile development. Differences in design and definition among missiles required interpretation and adjustment of reported data. Our goal was to characterize the terminal guidance system, including seeker and related avionics, while excluding control system and mid-course guidance elements. Because of this more systematic approach to compilation of guidance system characteristics, some air-launched missile data were altered from [2].

Of the eight surface-launched interceptors in the database, four were designed specifically as ballistic missile defense interceptors. The Sprint and the Spartan were the point and area defense interceptors associated with the Safeguard strategic missile defense system. The PATRIOT MM (multi-mode seeker) and ERINT-1 are point defense interceptors associated with current TMD efforts. The PATRIOT MM and ERINT-1 are the programs in the database that have progressed only through pre-EMD prototype efforts.

Among the attack missiles are two strategic systems, the Short-Range Attack Missile (SRAM) and the Air-Launched Cruise Missile (ALCM). Both of these systems are distinguishable from the tactical systems in that they have inertial terminal guidance systems. The ALCM is unusual for its very long-range capabilities and, along with the Harpoon, its air-breathing propulsion system.

One program attribute that is unquestionably important in determining the length of the development effort is the number of missiles launched during flight test. Data in Tables II-1, II-3, and II-5 enumerate the number of development missiles procured and the number launched during both the pre-EMD and EMD flight test programs. In our description of test missiles, we use the term "prototype missile" to describe missiles procured as a part of pre-EMD development and the term "development missile" to describe those procured in support of the EMD program. Various nomenclature were used within and among the different programs to describe test assets; we use these two standard terms. The number of test missiles procured is listed by contract, while the number of test missiles launched is listed by test phase.

For our analyses, we classified test phases into three broad categories, Pre-EMD testing, EMD development test and evaluation (DT&E) and initial operational test and evaluation (IOT&E). Because definitions for EMD test phases have differed over time and among the military services, some interpretation was required to classify the phases.

Navy EMD programs have been characterized by three test phases. The first phase, contractor demonstration test (CDT) or contractor test and evaluation (CTE), is when the contractor must demonstrate the basic capabilities of the missile. We classified this phase as DT&E. The second phase, Navy technical evaluation (NTE), sometimes referred to as technical evaluation (TECHEVAL) or joint test and evaluation (JTE), is when the government determines the capabilities of the missile and decides whether it is ready for operational evaluation (OPEVAL). OPEVAL is when the government evaluates the missile in an operational environment. We classified the last two phases as IOT&E. The three phases are generally run consecutively.

For Air Force programs, the phase analogous to CDT/CTE is Category I (Cat I) or development test and evaluation (DT&E). Air Force IOT&E or Category II (Cat II) phases have similarities with both the NTE/JTE and OPEVAL phases. Cat I and Cat II phases are associated with older Air Force programs and run consecutively. DT&E and IOT&E generally overlap in combined test programs. The classification of the Air Force phases into the two categories is obvious.

We found the Army programs had the least consistently structured test programs. Test phase nomenclature often differed from program to program and each test program consisted of many phases. Consequently, the Army test phases were the most difficult to classify. Descriptions of test phases and their classification for individual Army programs are provided in Appendix C.

C. DEVELOPMENT PROGRAM SCHEDULES

This section summarizes schedule data both in tabular and graphical form. The data are presented in a manner consistent with the way they were analyzed. We present program schedule data characterizing development through production start and initial operational capability (IOC), including pre-EMD prototype efforts.

Tables II-7, II-8, and II-9 present major milestones for each class of programs. In order to compare across programs, milestone dates were normalized to the common milestone, EMD start. We defined EMD start as the beginning of EMD contract efforts, which usually corresponds to EMD contract award. EMD start was used because it represents the most unambiguous base point common to all programs; normalized milestones are expressed as months from EMD start. Other schedule interval data include time from prototype start to prototype first launch, EMD first launch to first production, and first production to IOC.[1] Also included are average intervals for each mission group.

The time from development start to the first guided launch is consumed by various activities. These include missile design, fabrication and assembly of test hardware, and tests leading to initiation of the guided-launch program. These tests generally include hardware integrated simulation, captive-missile flight test (air-launched missiles), and non-guided launches, including separation/jettison (air-launched missile) testing. Often the first test missile launched is not self-guided but is controlled externally. Such unguided launches are meant to test the propulsion system and/or the aerodynamics of the missile; we refer to such launches as controlled test vehicle (CTV) launches.

The length of the interval from first guided launch to the first production delivery is driven by the length of the test program and the degree of concurrency between the test program and production. Test program length is determined by the number of missiles launched and the rate at which test launches are completed. Test program length is treated in more detail in the next section. Our analyses treat concurrency as a policy variable where decision-makers compare schedule against technical and cost risk.

The relationship between production start and IOC is less clear. It does appear that Army and Air Force programs require more time to reach IOC from the first production delivery than Navy programs. Average time from first production to IOC for Army and Air Force programs are 20.4 and 17.6 months compared to 13 months for Navy programs. Because definitions of IOC differ across programs, and because these differences are not easily characterized, analysis related to this milestone was limited.

Figures II-1, II-2, and II-3 display EMD milestones as expressed in months from EMD start for surface-launched interceptor, air-launched interceptor, and air-launched attack missile programs, respectively. Averages for all programs within each classification are plotted on the horizontal axes and values for individual programs are plotted on the vertical axes. Points above the 45-degree line represent values higher (longer time intervals) than the group average for a given milestone; those below represent values lower (shorter time intervals) than the average. Dispersion around the mean is greater for milestones that occurred later in the programs.

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1 We include no analyses for IOC, although we do report data for this milestone.

Table II-7. Program Milestones and Intervals for Surface-Launched Interceptor Missile Programs

Milestone	MIM-23B Improved HAWK	RIM-66C/67B SM-2	MIM-104A PATRIOT	PATRIOT MM	FIM-92A Stinger	Sprint	Spartan	ERINT-1
Calendar Dates								
Prototype Start	N/A	7/70	5/67	7/89	N/A	N/A	N/A	11/89
First Guided Launch, Prototype	N/A	—	11/70[a]	4/92	N/A	N/A	N/A	6/93
EMD Start	11/64	5/72	3/72	N/A	6/72	5/63	10/65	6/94
First Guided Launch, EMD	8/67	12/74	2/75	N/A	11/73	11/65	3/68	N/A
First Production Delivery	12/70	4/78	1/82	N/A	12/79	—	12/72	N/A
IOC	11/72	9/77	2/83	N/A	2/81	6/74	7/74	N/A
Months From EMD Start								
Prototype Start	N/A	-22	-58	N/A	N/A	N/A	N/A	-55
First Launch, Prototype	N/A	—	-16[a]	N/A	N/A	N/A	N/A	-12
EMD Start	0	0	0	N/A	0	0	0	0
First Guided Launch, EMD	33	31	35	N/A	17	30	29	N/A
First Production Delivery	73	71	118	N/A	90	—	86	N/A
IOC	96	64	131	N/A	104	133	105	N/A
Other Intervals (Months)								
Prototype Start to Prototype First Guided Launch	N/A	—	42[a]	33	N/A	N/A	N/A	43
EMD First Launch to First Production	40	40	83	N/A	73	—	57	N/A
First Production to IOC	23	-77	13	N/A	14	—	19	N/A

Note: N/A means not applicable. Dashes (—) mean data were not available.
[a] Controlled test vehicle.

Table II-8. Program Milestones and Intervals for Air-Launched Interceptor Missiles

Milestone	AIM-7F Sparrow	AIM-7M Sparrow	AIM-9L Sidewinder	AIM-9M Sidewinder	AIM-54A Phoenix	AIM-54C Phoenix	AIM-120A AMRAAM
Calendar Dates							
Prototype Start	N/A	8/76	6/71	N/A	N/A	N/A	2/79
First Launch, Prototype	N/A	—	4/72	N/A	N/A	N/A	8/81
EMD Start	7/66	4/78	7/72	2/76	12/62	9/77	12/81
First Guided Launch, EMD	3/68	4/80	10/73	2/78	5/66	4/80	5/85
First Production Delivery	1/76	1/83	3/78	—	3/73	8/82	9/88
IOC	4/76	1/83	5/78	9/82	12/73	12/86	9/91
Months From EMD Start							
Prototype Start	N/A	-20	-13	N/A	N/A	N/A	-34
First Guided Launch, Prototype	N/A	—	-3	N/A	N/A	N/A	-18
EMD Start	0	0	0	0	0	0	0
First Guided Launch, EMD	20	24	15	24	41	31	41
First Production Delivery	114	57	68	—	123	59	81
IOC	117	57	70	79	132	111	117
Other Intervals (Months)							
Prototype Start to Prototype First Guided Launch	N/A	20	10	N/A	N/A	N/A	30
EMD First Launch to First Production	94	33	53	—	82	28	40
First Production to IOC	3	0	2	—	9	52	13

Note: N/A means not applicable. Dashes (—) mean data were not available.

Table II-9. Program Milestones and Intervals for Air-Launched Attack Missiles

Milestones	AGM-65A Maverick EO	AGM-65D Maverick IIR	AGM-67A SRAM	AGM-84A Harpoon	AGM-86B ALCM	AGM-88A HARM	AGM-114 Hellfire
Calendar Dates							
Prototype Start	N/A	4/74	N/A	6/71	2/74	11/74	—
First Guided Launch, Prototype	N/A	10/75	N/A	12/72	9/76	10/76	—
EMD Start	7/68	10/78	11/66	9/72	2/78	9/77	9/77
First Guided Launch, EMD	12/69	12/80	7/69	3/74	8/79	4/79	10/78
First Production Delivery	8/72	10/83	3/72	2/77	11/81	11/82	10/83
IOC	2/73	2/86	8/72	7/77	12/82	11/83	7/86
Months From EMD Start							
Prototype Start	N/A	-54	N/A	-15	-48	-34	—
First Launch, Prototype	N/A	-36	N/A	3	-17	-11	—
EMD Start	0	0	0	0	0	0	0
First Guided Launch, EMD	17	26	32	18	18	19	13
First Production Delivery	49	60	64	53	45	62	73
IOC	55	88	69	58	58	74	106
Other Intervals							
Prototype Start to Prototype First Launch	N/A	18	N/A	18	31	23	N/A
EMD First Launch to First Production	32	34	32	35	27	43	57
First Production to IOC	6	28	5	5	13	12	36

Note: N/A means not applicable. Dashes (—) mean data were not available.

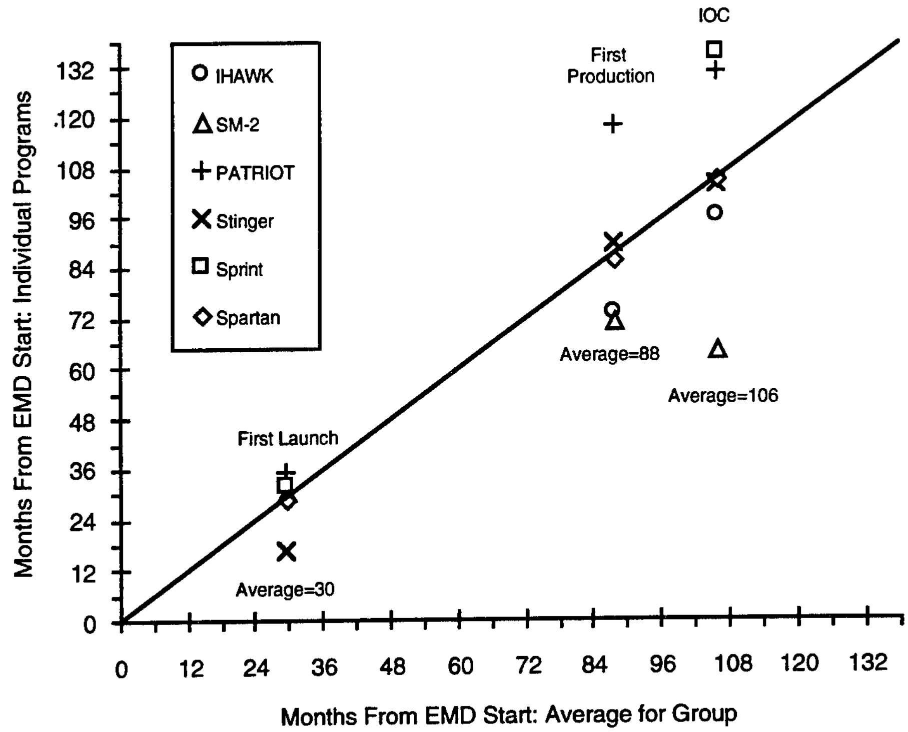

Figure II-1. EMD Milestones for Surface-Launched Interceptor Missile Programs

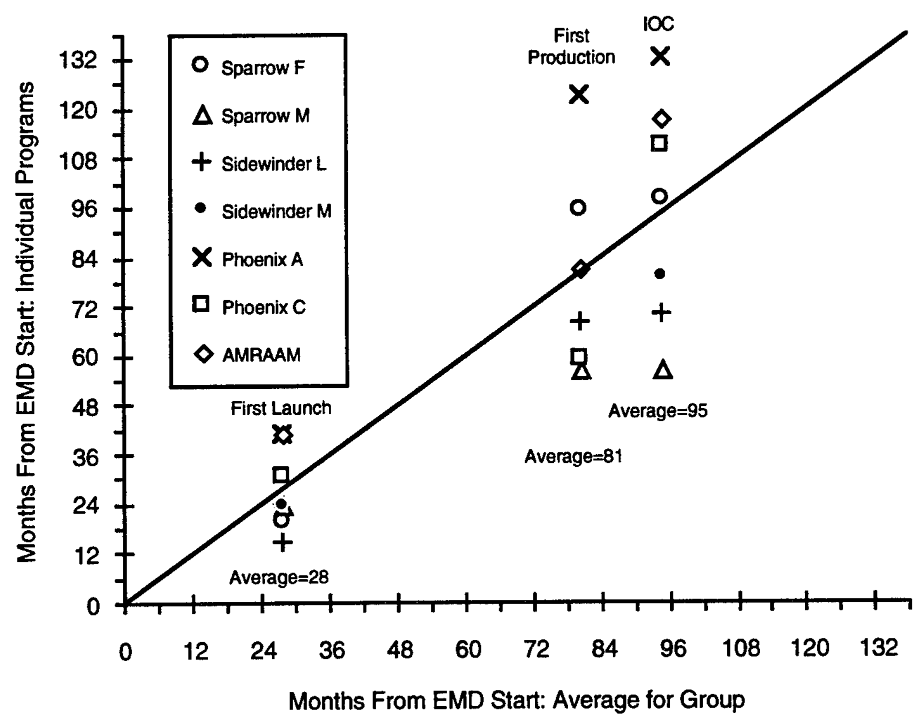

Figure II-2. EMD Milestones for Air-Launched Interceptor Missile Programs

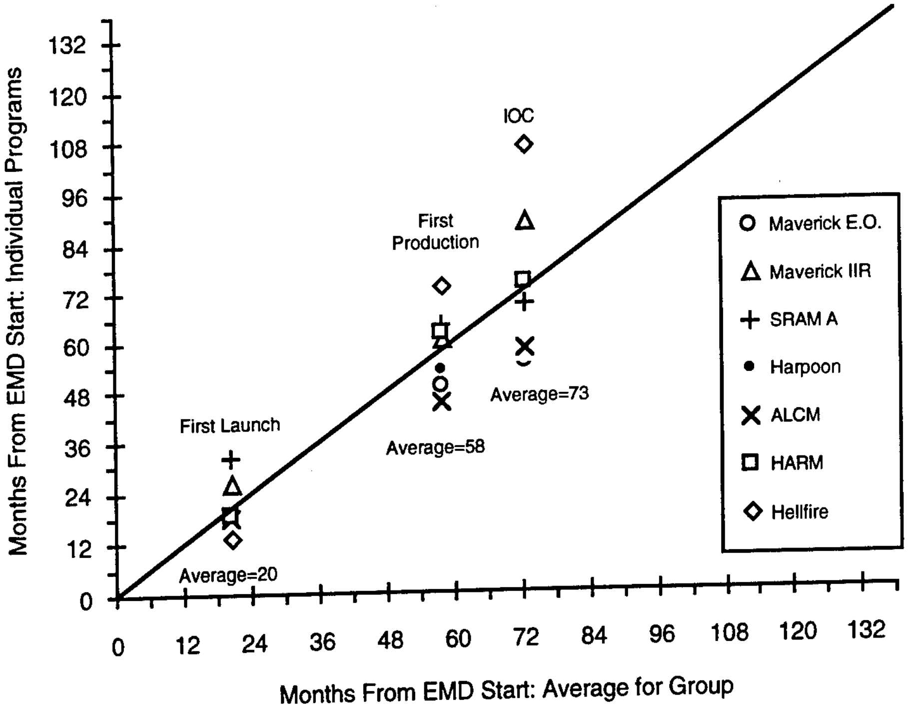

Figure II-3. EMD Milestones for Air-Launched Attack Missile Programs

Looking at variations in schedule intervals across programs in the context of program and missile characteristics, we can see that certain patterns emerge. On average, schedule intervals for interceptor programs were longer than those for attack programs. This is particularly evident for the interval from first guided launch to first production delivery. This interval was also longer for programs in which a large number of test missiles were launched. Missiles with heavier and more complex guidance systems tend to take longer to develop, both to first flight and to first production. Our statistical tests of these and other schedule drivers are described in the next chapter.

D. FLIGHT TEST PROGRAM

Tables II-10 and II-11 summarize test program data for surface-launched interceptors and air-launched interceptor and attack missiles. We present data by program and phase, including test start and end dates and the number of missiles fired. For most programs, we have a complete accounting of the test phases comprising the EMD launch program. We also have data on six pre-EMD prototype test programs.

Table II-10. Test Program Summary, Surface-Launched Interceptor Missiles

Program	Phase[a]	Number of Launches	Test Start	Test End	Test length (Months)	Months per Launch
IHAWK	R&D	25	8/67	10/68	14	0.58
	Engineering Test	16	2/69	12/69	10	0.66
	CORE Test Program	10	3/70	7/70	4	0.45
	Performance Demonstration	17	1/71	4/71	3	0.18
	Initial Production Test	23	5/71	7/72	14	0.64
	IOT&E	8	7/72	8/72	1	0.15
PATRIOT	Proof of Principle and Evaluation	11	2/27/75	2/6/76	11.3	1.13
	Phase II Engineering Test	8	12/2/76	6/2/77	6.0	0.85
	Phase III Engineering Test	27	11/4/77	12/10/79	25.2	0.97
	Operational Testing	9	2/5/80	3/26/80	1.6	0.21
	Development Testing	4	5/5/80	6/25/80	1.7	0.56
PATRIOT MM	Pre-EMD	4	4/11/92	10/26/93	18.5	6.17
SM-2	Development Testing	14	12/74	9/76	21	1.62
	OT&E	10	9/76	11/76	2	0.22
	Development Testing-III	9	12/76	5/77	5	0.62
	Operational Testing-III	7	7/77	7/77	1	0.16
Stinger	Guided Test Vehicle	16	11/73	7/75	20	1.33
	Design	18	7/75	1/76	6	0.36
	Prototype Qual. (Contractor)	32	2/76	10/76	8	0.26
	Prototype Qual./OTII (Army)	46	10/76	4/77	6	0.13
	Production Prototype	18	7/77	11/77	4	0.24
Sprint	Development Testing	42	11/65	8/70	57	1.39
	Operational Testing	32	10/70	12/73	38	1.23
Spartan	Development Testing	15	3/68	3/70	24	1.71
	Operational Testing	20	4/70	6/73	38	2.00
ERINT-1	Pre-EMD	4	6/26/93	6/2/94	11.2	3.74

[a] See the list of abbreviations at the end of this paper for definiations of abbreviations used here.

The variable of particular interest is the time between launches as expressed as months per launch. This is the measure used to characterize launch rate. The months per launch variable in Tables II-10 and II-11 was calculated as follows:

$$\text{Months per launch} = \left[\text{test phase duration} / (\text{test phase launches} - 1)\right],$$

where the test phase duration is the number of months separating the first and last launches, hence the subtraction of one launch from the denominator.

The length of the individual test phases is determined by the number of missiles tested and the rate at which they are fired. One source of much schedule optimism at program start is the over-estimation of launch rates (under-estimation of months per launch). We have also seen that major technical problems in development may require increases in the number of development missiles tested and subsequent program schedule stretches. In our analyses, emphasis was on explaining the variability in launches per month between programs because the latter problem does not lend itself to prediction.

Table II-11. Test Program Summary, Air-Launched Missiles

Program	Phase[a]	Number of Sites	Number of Launches	Test Start	Test End	Test length (Months)	Months per Launch
Sparrow F	CDT	1	7	3/15/68	11/6/68	7.8	1.30
	NTE	1	42	12/10/69	2/2/72	25.8	0.63
	OPEVAL I	2	25	5/4/72	12/29/72	7.9	0.33
	OPEVAL II	2	25	8/73	9/74	13.0	0.54
Sparrow M	CTE	1	13	4/2/80	8/27/80	4.8	0.40
	JTE	1	22	8/27/80	2/24/81	6.0	0.28
Sidewinder L	Pre-EMD	1	11	4/72	7/73	15.0	1.49
	CTE	1	10	10/73	5/74	7.0	0.78
	JTE/OPEVAL/ IOT&E	2	50	8/74	12/75	16.0	0.33
Sidewinder M	CTE	1	10	2/78	5/79	15.0	1.67
Phoenix A	CDT (FSD)	1	26	5/12/66	12/24/69	43.5	1.72
	CDT (TP/VE)	1	27	3/9/70	10/19/73	43.4	1.67
	NTE	1	11	6/5/73	6/27/74	12.7	0.85
	OPEVAL	1	24	8/23/74	7/13/76	22.7	0.99
Phoenix C	CTE	1	10	4/17/80	3/31/82	23.4	2.63
	NTE	1	6	5/82	11/82	6.0	1.20
	OPEVAL	1	15	3/83	6/84	15.1	1.08
AMRAAM	DT&E/IOT&E	3	91	5/14/85	6/15/89	49.1	0.55
Maverick EO	Category I	1	15	12/18/69	11/30/70	11.4	0.81
	Category II	1	37	2/10/71	9/8/71	6.9	0.19
Maverick IIR	DT&E/IOT&E	1	26	12/4/80	8/17/82	20.4	0.84
SRAM	Category I/Cat II	1	38	7/29/69	7/7/71	23.3	0.63
Harpoon	Pre-EMD	1	12	12/20/72	12/10/73	11.7	1.06
	CTE/NTE	1	33	3/31/74	6/27/75	14.9	0.47
	OPEVAL	1	33	8/1/75	3/1/77	19.0	0.60
ALCM	Pre-EMD	1	3	9/9/76	11/30/76	2.7	1.35
	DT&E	1	10	8/3/79	1/22/80	5.7	0.63
	DT&E (follow-on)	1	11	6/10/80	5/5/81	10.8	1.09
HARM	Pre-EMD[b]	1	9	2/25/76	6/22/77	15.9	2.00
	CTE[b]	1	18	2/28/79	10/31/80	20.1	1.18
	NTE/OPEVAL/ IOT&E	2	40	8/6/81	10/5/82	14.0	0.36

a See the list of abbreviations at the end of this paper for definiations of abbreviations used here.
b Includes CTV launches.

Certain patterns in the variability of launches per month become apparent when examining the data in Tables II-10 and II-11. Test phases that occurred later in the program, particularly initial operational testing had higher launches per month. Interceptor programs took longer between launches than air-to-surface programs, while surface-launched interceptors required less time between launches than air-launched interceptors. ballistic missile defense (BMD) interceptors show the longest average time between launches. The two programs that had a mix of launches from both aircraft and surface ships, the Sparrow M and the Harpoon, experienced higher rates than otherwise comparable air-launched missile programs. Air-launched programs that concurrently used multiple test sites also had higher rates (no surface-launched interceptor program used multiple test sites concurrently). We test these and other possible determinants of launches per month in Chapter III.

E. EARLY PRODUCTION

Data were collected characterizing the early production periods for a portion of our sample programs. Table II-12 presents production milestones and other data describing early procurement lots for 18 programs. Included are data for both pilot production and production lots. Data for one second-source program, the Sparrow F, are also included.

Production times were measured as both the number of months from long-lead release (LL) and full-funding release (FF) to the first missile delivery for a given lot of missiles. The full-funding release date generally corresponds to the contract award date. We included measures of concurrency for the first production lot in each program. We define the first production lot as the first lot from which substantial test assets were not drawn. The measures were the spans of time between the end of the test program (defined as the end of the OPEVAL, IOT&E, or Cat II phase) and the long-lead release and full-funding release milestones. The more overlap between the test programs and production (concurrency), the smaller the values of the two measures. In order to derive a full set of concurrency measures, we estimated dates for long-lead release for the IHAWK, SM-2, Spartan, Sparrow F, and Maverick EO programs and full-funding release for the Sidewinder L program. The estimates were made based on a regression equation relating long-lead to full-funding intervals. The regression equation is presented in Appendix D.

Certain outliers and anomalies exist in the data. The longest production time intervals were for the first production lot of the Phoenix C program. Long-lead release for this lot occurred on the same date as for the pilot production lot. Another unusually long production time was for the Maverick IIR's FY83 production lot. Outliers for the concurrency measures include both Phoenix development programs. Because of the stretch in the Phoenix program due to the F-111B cancellation,[2] a large number of test launches were accomplished before OPEVAL, many of which resembled operational tests; consequently, production decisions were made long before OPEVAL even started. In the case of the Phoenix C, the first three production lots were relatively small, making them similar to pilot production lots, and were therefore contracted for early in the program.

2 The Phoenix missile was originally designed for the F-111B. The missile was not fielded operationally until the F-14A was available.

Table II-12. Early Production Experience

System	Description	Quantity	Long Lead (LL)	Full Funding (FF)	First Delivery	Time in Months: LL to First Delivery	FF to First Delivery	Test End to LL	Test End to FF
IHAWK	FY69	100	—	1/69	12/70	—	23		
	FY70	330	12/69[a]	8/70	12/71	24[a]	16	-32[a]	-24
PATRIOT	FY80	155	11/79	9/80	1/82	26	16	-7	3
	FY81	92	2/81	8/81	7/83	29	23	—	—
	FY82	176	11/81	5/82	9/83	22	16	—	—
Stinger	Low Rate	258	12/77	4/78	12/79	24	20	8	13
	FY79-81	4,971	—	4/79	2/81	—	22	—	—
SM-2	Pilot	22	12/75[a]	6/76	4/78	27[a]	22	-18[a]	-13
	Initial	36	—	6/77	2/79		20	—	—
Spartan	First Lot		6/70[a]	10/70	12/72	30[a]	26	-36[a]	-32
Sparrow F	FY68 Pilot	65	3/68	6/69	7/70	28	13	—	—
	FY71 Pilot	29	—	9/70	12/71	—	15	—	—
	FY72 Pilot	100	—	6/72	8/73	—	14	—	—
	FY73 Pilot	150	—	5/73	8/74	—	15	—	—
	FY75	600	2/74[a]	11/74	1/76	22[a]	14	-7[a]	2
Sparrow F	FY74 Qual.	15	7/74	—	3/76	20	—	—	—
(second source)	FY75 Pilot	70	8/75	—	6/77	22	—	—	—
Sidewinder L	FY76	1,534	4/76	12/76[a]	3/78	23	15[a]	4	13[a]
Phoenix A	FY72	240	12/70	12/71	3/73	27	15	-67	-55
	FY73	180	—	12/72	2/74	—	14	—	—
	FY74	284	—	12/73	2/75	—	14	—	—
Phoenix C	FY80	60	9/79	11/79	8/82	35	33	-57	-55
	FY81	60	6/81	10/81	7/83	25	21	—	—
	FY82	72	6/82	10/82	6/84	24	20	—	—
AMRAAM	FY86	180	11/86	10/87	9/88	22	11	-31	-20
	FY88	400	12/87	7/88	8/89	20	13	—	—
	FY89	1,270	10/88	7/89	8/90	22	13	—	—
Maverick EO	Option A	2,000	10/70[a]	7/71	8/72	22[a]	13	-11[a]	-2
	Option B	5,000	—	11/72	1/74	—	14	—	—
	Option C	10,000	—	10/73	11/74	—	13	—	—
Maverick IIR	FY82	200	4/82	9/82	10/83	18	13	-4	1
	FY83	900	—	4/83	11/85	—	31	—	—
	FY84	1,980	4/84	4/85	8/86	28	16	—	—
SRAM	FY71	122	6/70	1/71	3/72	21	14	-13	-6
Harpoon	Pilot	150	1/74	7/74	8/75	19	13	—	—
	First	345	6/75	2/76	2/77	20	12	-21	-13
ALCM	FY80	225	10/79	3/80	11/81	25	20	-19	-14
	FY81	480	10/80	—	11/82	25	—	—	—
	FY82	440	10/81	—	10/83	24	—	—	—
HARM	First	80	1/81	12/81	11/82	23	12	-21	-10
Hellfire	FY82	680	8/81	3/82	10/83	26	19	8	15
	FY83	3,971	—	1/83	10/84	—	21	—	—
	FY84	4,651	—	6/84	3/86	—	21	—	—

Note: Dashes (—) mean data were not available.

a Estimates.

Looking across the values for the majority of the programs, we see no apparent pattern in the variability of the production times. By examining the measures of concurrency (disregarding the Phoenix programs), we find seven programs that are essentially non-concurrent and seven that are concurrent. For the seven non-concurrent programs, the PATRIOT, Stinger, Sparrow F, Sidewinder L, Maverick IIR, and Hellfire, full-funding and long-lead release occurred after or slightly before test completion. For the seven concurrent programs, the IHAWK, SM-2, Spartan, AMRAAM, Harpoon, ALCM, and HARM, long-lead release occurred between 18 and 36 months and full-funding release between 10 and 32 months before test end. Of the concurrent programs, the Spartan and AMRAAM show the most concurrency. The SRAM and Maverick EO are on the borderline between the two classes of programs. Analyses of production data in the next chapter explore other ways of characterizing concurrency.

III. DATA ANALYSIS

The four program intervals we analyzed are: (1) time to first guided launch, (2) length of development flight test, (3) early production times, and (4) program length from first guided launch. The subjects of analysis follow from a previous IDA report [2]. The relationships between the four intervals are depicted in Figure I-1 in Chapter I, where a notional missile development program is presented. First guided launch marks the culmination of early design and manufacturing activity and initiates the guided-launch flight test program. During flight testing, information is gathered to be used both in refining the missile design and in supporting production decisions. The concurrency of development and production can be seen in the overlap of development flight testing and early production activity. This production activity is characterized by production times for the early procurement lots, expressed as the interval between long-lead and full-funding release and the delivery of the first production missile. Originally, we wanted to develop a single equation to estimate the interval spanning total EMD program length as defined by the period from EMD start to the delivery of the first production missile. The equation would serve as an aggregate check on a total EMD length estimate derived from combining estimates for the other intervals. The drivers of schedule intervals before and after first guided launch are different enough that estimating a single equation characterizing the program as a unified whole is neither practical nor intuitively appealing. Instead, we estimated the interval between first guided-launch and the first production delivery.

A. APPROACH

We used least-squares regression techniques as the primary method to define and test time-estimating relationships (TERs) for the intervals examined. This was the approach taken in previous IDA studies on schedule estimating. For selected intervals we also employed a "frontier function" approach, building upon methods presented in the economics and operations research literature [55]. The results of the frontier function method are presented in Appendix E. For both methods, schedule intervals measured in months were treated as dependent variables and related to independent variables, which we hypothesized to be schedule drivers. In the case of least-squares regressions, the TERs are defined by parameter estimates on the independent variables determined by minimizing the squared errors of the regression line from the actual data.

Because some TERs took on the intrinsically linear multiplicative form $Y = ax^b$, we were able to employ standard linear regression techniques. To do this, the equation was transformed to a log-log form. The classical normal regression assumption is that the residuals are additive and are normally distributed in log-log space with an expected value and mode of zero. When the equation is transformed from the log-log form back to its original form, the assumption implies that the resulting residuals are multiplicative and distributed lognormally with a mode of one. Because the lognormal distribution is right-skewed, the expected value and mode of the residuals were no longer equal; the expected value is not one, as desired. Because of this, the unadjusted multiplicative equation would yield values of the dependent variable that correspond to the mode. We needed to make an adjustment to address the re-transformation bias so that the TER would yield the expected value.

The adjustment was made to the relevant TERs by adding one-half of the regression mean square error ($\hat{\sigma}^2$) to the intercept term of the log-log equation before its transformation into the multiplicative form. After the intercept term was transformed into a multiplicative constant, we calculated an adjustment factor (adjusted constant term/unadjusted constant term) where the adjustment factor is always greater than one. In reporting the estimating relationships, we report the adjusted multiplicative equation along with the factor, so the equation can be back-adjusted to yield the mode (most likely value).

Other information describing the estimating relationships include the number of data observations used in the regression (N), R^2, adjusted R^2, the standard error of the estimate ($\hat{\sigma}$) and levels of statistical significance for each of the parameter estimates. R^2 measures the proportion of the total variance in the data explained by the model; adjusted R^2 presents this information adjusted for the number of independent variables in the regression. R^2 and adjusted R^2 are calculated from the data and model after they are transformed back from log space to arithmetic space. $\hat{\sigma}$ is calculated in log space; it can be converted into minus/plus percentages of the Y values in the original space by the relationships: $(e^{-\hat{\sigma}}) - 1$ and $(e^{+\hat{\sigma}}) - 1$. We also calculated standard errors based on the additive residuals in arithmetic space, $\hat{\sigma}'$. The level of statistical significance for a parameter estimate describes the probability that we were incorrect when we rejected the null hypothesis that $b = 0$ (i.e., that the independent variable of interest had no effect on schedule length).[1] Our rule of thumb was to exclude

1 For the parameter estimates on 1/0 dummy variables, which have been transformed to yield multiplicative factors, the null hypothesis is that $b = 1$.

variables whose parameter estimates were not significant at the .1 level. Where we report probability levels, values that were less than .01 have been rounded to .01.

Additional considerations were introduced in the estimation of TERs for average months per launch (M/L). The values for the dependent variable used when estimating the TERs were means calculated for each test phase, where the number of launches varies between test phases. The effect of this was to create non-constant disturbance variances (heteroscedasticity). The variance of each disturbance term can be characterized as $\mathrm{Var}[\varepsilon_i] = \sigma_i^2 = \sigma^2\omega_i$. The effect of this for our estimation problem was that the ordinary least squares (OLS) parameter estimates were no longer the minimum variance estimators, although they were still unbiased. This led us to a weighted least-squares approach to estimation [56]. In our case $\omega_i = 1/N_i$, where N_i is the number of missile launches in each test phase less one. The weighting scheme is to multiply each Y_i and $\hat{Y}_i$ by $(1/\omega_i)^{.5} = N_i^{.5}$.

However, this approach presented us with a second problem. Under the weighted least-squares scheme, $\hat{\sigma}_i^2$ would vary with the number of launches. This means that the adjustment for re-transformation bias would vary depending upon the number of launches in the test phase. The variation would be systematic with the adjustment factor increasing with decreases in the number of launches. In order to avoid this anomaly, we estimated the weighted regression using nonlinear least squares, where no re-transformation bias is encountered. When we employed non-linear least squares we assumed that the error terms were additive. The disadvantage of using non-linear least squares was that we had to depend upon asymptotic standard errors in order to perform hypothesis tests on parameter estimates. Because the data samples used to estimate the M/L regressions were relatively large, this disadvantage was minimized.

B. TIME TO FIRST GUIDED LAUNCH

In developing a regression model to estimate the number of months (time) required from EMD or pre-EMD start to first guided launch (TFGL), we used the analyses of air-launched interceptors in [2] as a point of departure. Because it was not possible to collect detailed characteristic data on most pre-EMD prototype missiles, we employed the same characteristics for both EMD and pre-EMD missiles—we made the reasonable assumption that the physical characteristics of the pre-EMD and EMD missiles are similar.

Attempts to use missile characteristics as explanatory variables were fruitful. Of particular merit were variables characterizing guidance size and complexity. The guidance system is generally the component of the missile with the highest value and the subject of the most technological advance. As such, development of the guidance system typically sets the pace of a missile's development. Guidance system parameters used include Guidance Weight and a measure of guidance system packaging complexity. Obviously, weight is not an ideal measure of guidance complexity because a major goal in newer, more advanced systems is the miniaturization of components. If we were focusing on a narrow class of missiles, weight probably would not explain much variation in time to first guided launch. However, our database is diverse in that guidance weights range from 3.7 to 179 pounds.

In addition to Guidance Weight, we developed a measure to serve as a proxy for guidance system packaging complexity, Power Density.[2] This measure was expressed as:

$$\text{Power Density} = \frac{\text{Guidance system input power (watts)}}{\text{Guidance system volume (cubic inches).}}$$

Unfortunately, this measure was available for only a subset of the sample. Other variables of interest included 1/0 indicator variables designating pre-EMD prototype programs (Pre-EMD), EMD programs that were preceded by prototype efforts (PROTO), modification programs (MOD), interceptor missile programs (Interceptor), and surface-launched missile programs (SUR).

With the full data sample, where the guidance complexity variable (Power Density) could not be used, the best predictors of time to first guided launch include guidance weight and indicator variables for modification and interceptor programs. We refer to this equation as the "baseline TER." The resulting regression equation and measures of statistical significance and model fit are:

$$\text{TFGL} = \underset{(.01)}{7.716}\ (\text{Guidance Wt.})^{\underset{(.01)}{.220}}\ \underset{(.01)}{1.712}^{(\text{Interceptor Dummy})}\ .774^{(\text{Mod Dummy})}$$

$N = 28$ $R^2 = .75$ Adjusted $R^2 = .72$ $\hat{\sigma} = .196$ $\hat{\sigma}' = 4.7$ Intercept adjustment = 1.017

Significance levels are in parentheses below the parameter estimates. N is the number of observations and $\hat{\sigma}$ is the standard error of the estimate. The regression results show all parameter estimates significant at the .01 level. All 28 programs are represented in the data sample. This includes 20 EMD programs and 8 pre-EMD programs. All parameter estimates have intuitively pleasing coefficients. The large coefficient (>1) on the Interceptor

2 A cruder measure of guidance complexity, (guidance weight)/(missile cross-section), which was used successfully in [2], was not statistically significant when included as an independent variable with surface-launched interceptors included in the database.

Dummy accounts for the additional complexity associated with the interceptor mission. The coefficient (<1) on the Mod Dummy is consistent with the ability to achieve first launch earlier if a significant portion of the missile is "off-the-shelf."

Independent variables indicating a pre-EMD program, or an EMD program with a pre-EMD prototype were not statistically significant. Other variables that did not prove statistically significant were indicator variables for guidance system types; the types included active radar, passive radar, command/inertial, and infrared.

Figure III-1 plots time to first guided launch predicted by the above equation against program actuals. Values below the 45-degree line are overestimated by the model; values above the line are underestimated. All of the surface-launched interceptors and important outliers are identified in the figure. Notable outliers include the ERINT-1, Sidewinder M, and Sidewinder L Pre-EMD. Table III-1 summarizes the prediction errors associated with the regression.

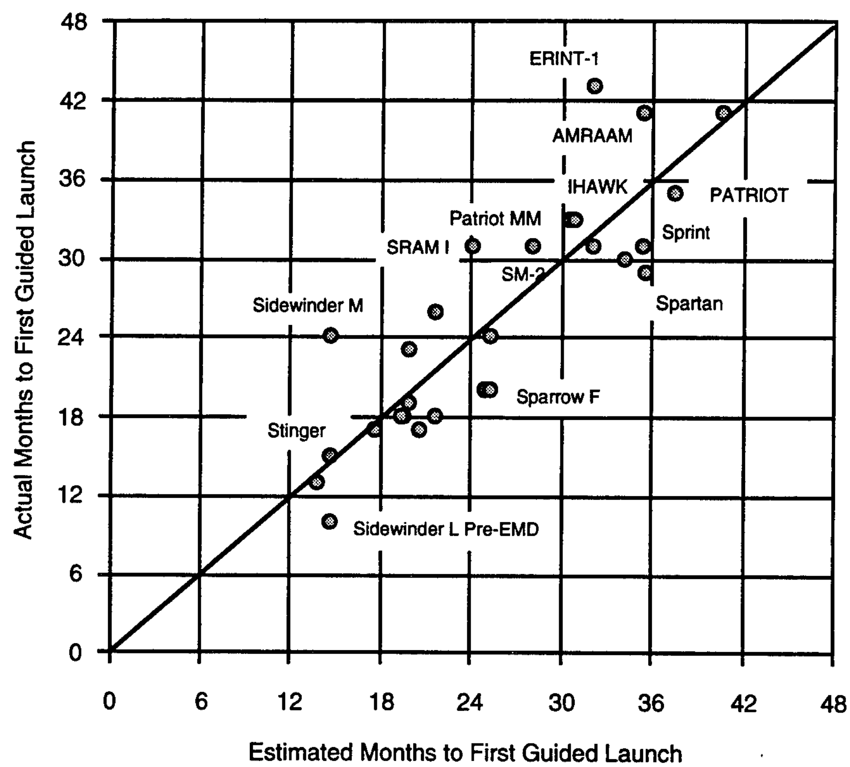

Figure III-1. Predicted Versus Actual Time From EMD Start to First Guided Launch: Baseline Model

Table III-1. Prediction Error Summary: Baseline TER

Program	Actual Value (Months)	Predicted Value (Months)	Error (Actual – Predicted)	Multiplicative Error (Actual/Predicted)
IHAWK	33	30.6	2.4	1.10
PATRIOT	35	37.6	-2.6	0.95
SM-2 Blk-1	31	28.1	2.9	1.12
Stinger	17	17.6	-0.6	0.98
Sprint	30	34.3	-4.3	0.89
Spartan	29	35.6	-6.6	0.83
PATRIOT MM	33	30.8	2.2	1.09
ERINT-1	43	32.1	10.9	1.36
Sparrow F	20	24.9	-4.9	0.82
Sparrow M Pre-EMD	20	25.3	-5.3	0.80
Sparrow F	24	25.3	-1.3	0.96
Sidewinder L Pre-EMD	10	14.7	-4.7	0.69
Sidewinder L	15	14.7	0.3	1.04
Sidewinder M	24	14.7	9.3	1.66
Phoenix A	41	40.7	0.3	1.02
Phoenix C	31	32.0	-1.0	0.98
AMRAAM Pre-EMD	31	35.5	-4.5	0.89
AMRAAM	41	35.5	5.5	1.18
Maverick EO	17	20.7	-3.7	0.84
Maverick IIR Pre-EMD	18	21.7	-3.7	0.84
Maverick IIR	26	21.7	4.3	1.22
SRAM	31	24.1	6.9	1.31
Harpoon Pre-EMD	18	19.7	-1.7	0.93
Harpoon	18	19.7	-1.7	0.93
ALCM	18	19.5	-1.5	0.94
HARM Pre-EMD	23	19.9	3.1	1.18
HARM	19	19.9	-0.9	0.97
Hellfire	13	13.9	-0.9	0.95

The next step was to estimate the TER with the Power Density variable included. We call this the augmented TER. The sample size for the augmented TER decreases from 28 to 16. The resulting regression equation and measures of statistical significance and model fit are:

$$\text{TFGL} = 6.889\ (\text{Guidance Weight})^{.318}\ (\text{Power Density})^{.172}\ 1.330^{(\text{Interceptor Dummy})}$$

(.01) (.01) (.02)

$N = 16$ $R^2 = .88$ Adjusted $R^2 = .85$ $\hat{\sigma} = .177$ $\hat{\sigma}' = 4.2$ Intercept adjustment = 1.016

Most notable when comparing the baseline and augmented equations is the large decrease in the parameter estimate for the Interceptor Dummy. On average, interceptor missiles in our sample have higher power densities than attack missiles, 0.85 watts/cubic inch compared with 0.23 watts/cubic inch. This indicates that some of the additional complexity associated with interceptor missiles is explained by the power density. There were only three modification programs in this data sample, the Sparrow F, and Sidewinder L EMD and Pre-EMD. When both Mod Dummy and Power Density were included in the regression, neither variable was statistically significant, although the Mod Dummy was the strongest of the two. The three modification programs represent the lower end of the interceptor missiles in terms of power density—0.25 watts/cubic inch compared with 1.15 watts/cubic inch for the remaining interceptors. Thus, in this sample the interceptor, modification, and power density effects are entangled. Figure III-2 plots time to first guided launch predicted by the augmented equation against program actuals.

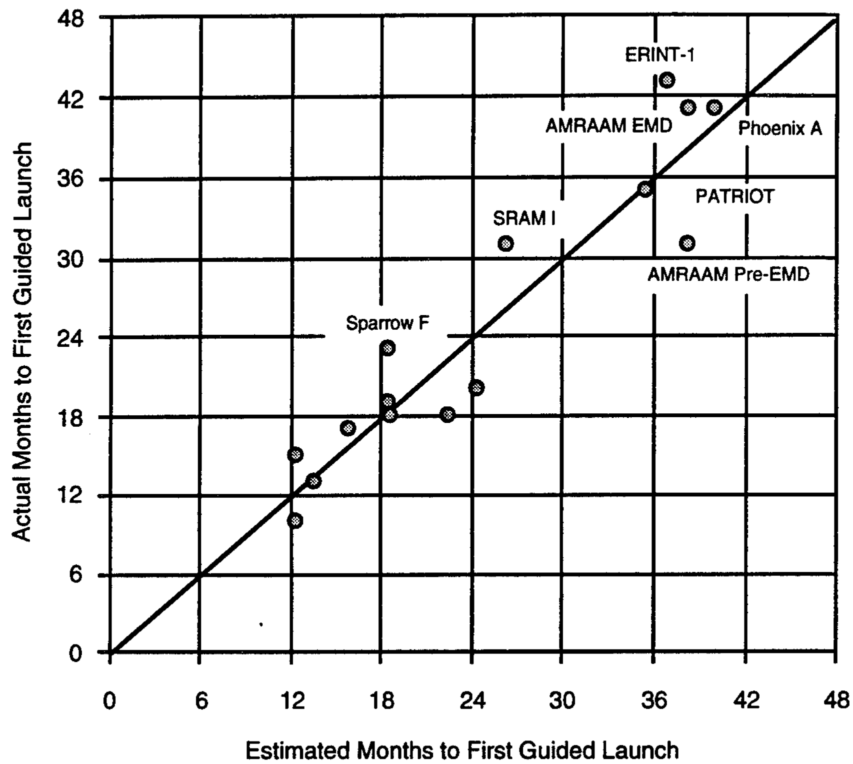

Figure III-2. Predicted Versus Actual Time From EMD Start to First Guided Launch: Augmented Model

We see from Figure III-2 that by adding the Power Density variable, the TER now does a better job at estimating programs for more complex missiles such as the AMRAAM and ERINT-1. The missiles with the highest power densities tend to be those missiles with active radar guidance; within this group the AMRAAM and ERINT-1 have the highest power densities. Table III-2 summarizes the prediction errors associated with the regression.

The analyses show that characteristic and programmatic variables explain much of the variance in the time to first guided launch. The use of guidance density as an additional variable to account for development complexity looks promising. However, given the limited data sample for which this measure was available, it was difficult to disentangle its effects from the interceptor and modification effects.

Table III-2. Prediction Error Summary: Augmented TER

Program	Actual Value (Months)	Predicted Value (Months)	Residual (Actual – Predicted)	Multiplicative Error (Actual/Predicted)
PATRIOT	35	35.5	-0.5	0.99
Stinger	17	15.9	1.1	1.07
ERINT-1	43	36.8	6.2	1.17
Sparrow F	20	24.4	-4.4	0.82
Sidewinder L Pre-EMD	10	12.5	-2.5	0.80
Sidewinder L	15	12.5	2.5	1.20
Phoenix A	41	40.1	0.9	1.02
AMRAAM Pre-EMD	31	38.2	-7.2	0.81
AMRAAM	41	38.2	2.8	1.07
SRAM	31	26.3	4.7	1.18
Harpoon Pre-EMD	18	22.4	-4.4	0.80
Harpoon	18	22.4	-4.4	0.80
ALCM	18	18.7	-0.7	0.96
HARM Pre-EMD	23	18.5	4.5	1.25
HARM	19	18.5	0.5	1.03
Hellfire	13	13.6	-0.6	0.95

C. FLIGHT TEST

Our approach to estimating flight test duration consisted of two steps. First, regression analysis was employed using data presented in Tables II-10 and II-11 (Chapter II) to estimate months per launch. Each months-per-launch value was associated with a development program and a test phase. Given estimated values for months-per-launch, flight test program length can be derived from the following relationship:

$$\text{Test Phase Duration} = (\text{number of launches} - 1) \times \text{months/launch.}$$

A single launch is subtracted from total launches because the first launch marks the beginning of the test phase; no time within the test phase is associated with accomplishing that launch. The required number of test launches is taken as a variable decided upon outside the model. We also estimated an equation for the number of test missiles, to be used as a check against the number of test launches proposed at program start.

We found that much of the variation in months per launch can be explained by technological and program variables. These include:

- guidance weight,
- whether the missile had an interceptor or attack mission (Interceptor),

- if it was an interceptor, whether its primary mission was ballistic missile defense (BMD),
- whether the missile was surface launched (SUR),
- what type of test phase was being estimated, pre-EMD, DT&E, or IOT&E
- the cumulative quantity of the missile launches (Q), and
- the number of test sites concurrently employed (NSITES).

In the data, the Interceptor, BMD, SUR, and test phase categories are represented by 1/0 dummy variables.

Guidance weight was used as a proxy for the technical complexity of the hardware being tested. The hypothesis was that the more complex the hardware being tested, the more time it would take to prepare for each launch event. Months per launch were expected to be higher for interceptor missiles than for attack missiles. Air-intercept testing is generally more difficult because the availability and preparation of air targets are fundamentally more problematic than surface targets, and interceptor scenarios are generally more complex; they often include active countermeasures. As noted before, interceptor missiles tend to have a higher degree of hardware complexity. Anti-ballistic missile testing adds yet another layer of complexity to testing. Because of the difficulties associated with airborne launch platforms, we expected that testing of air-launched missiles would take longer than testing of surface-launched missiles. Two programs, the Sparrow M and Harpoon, had test launches performed both from aircraft and surface ships. The data show higher rates for these programs, particularly in the case of the Sparrow M. In order to account for the two types of testing, we assigned a value of .5 to the SUR dummy variable for these programs.

Launch rates were also expected to differ depending upon the purpose of the test phase. Pre-EMD and DT&E test phases were expected to include more intense data reduction and analysis activities leading to hardware changes when compared with IOT&E test phases. Also, the higher relative maturity of development hardware and more general "learning" effects were expected to result in higher launch rates for test phases later in the program. In order to isolate the learning phenomena from the test phase effects, we provided for a progress curve relationship by including cumulative quantity at the test phase midpoint (Qm_i) as a variable. The progress curve effect was implemented in a way analogous to a unit-cost progress curve. Each test phase was treated as a production lot and average months per launch for each phase as the lot average unit cost. Test phase midpoints between the cumulative quantities of missiles launched at the beginning and end of phase i (Q_{i-1} and Q_i) were calculated iteratively using the usual lot midpoint equation:

$$Qm_i = \left\{ [(Q_i + .5)^{b+1} - (Q_{i-1} + .5)^{b+1}] / [(Q_i - Q_{i-1})(b+1)] \right\}^{1/b},$$

where b is the parameter estimate on the Qm_i variable.

For most programs, we had multiple data points, each representing a test phase. Air Force, Navy, and Army test programs do not follow the same structure, so some interpretations were necessary when classifying test phases into global categories. After examining the data and applying our knowledge about the nature of the test programs, we classified the test phases into three categories. The three categories consist of: pre-EMD (or prototype) testing; development test and evaluation (DT&E), including Navy CDT, CTE, and DT, Air Force Category I and DT&E; and initial operational test and evaluation (IOT&E), including Navy NTE, JTE,[3] OPEVAL and OT, and Air Force Category II and IOT&E. The Army used differing nomenclature from program-to-program. For the IHAWK, we categorized the R&D and Engineering Test as DT&E while the CORE and Performance Demonstration/Initial Production Test/IOT&E phases were classified as IOT&E; the IOT&E phases were considered so because they used production missiles in testing. For the PATRIOT all test phases besides OT were considered DT&E. For the Stinger, the GTV, Design, and contractor Prototype Qualification were considered DT&E, while the government Prototype Qualification/OTII test phase was considered IOT&E. The Sprint, Spartan, and ERINT-1 classifications are obvious.

In some programs, development testing and initial operational testing were performed in combined programs. In terms of the dummy variable scheme, the baseline test phase was DT&E. Given this, we distinguished the joint DT&E/IOT&E programs by using the proportion of IOT&E launches in each joint program as the value for the IOT&E dummy variable. In the case of the AMRAAM, where no breakout of individual launches was available, we assumed a 50/50 split. The resulting values are included in Table III-3.

We also considered the number of major test sites at which testing took place concurrently (NSITES). The expectation is that the more test sites employed, the higher the launch-rate attainable. In some programs, a small number of specialized tests took place at separate sites. In our database, these were not considered additional test sites. In one

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3 An argument could be made that Navy NTE/JTE test phases should be classified as DT&E phases instead of IOT&E phases; however, the data show that in terms of months per launch, NTE/JTE are more closely aligned to OPEVAL than to CDT/CTE.

program, the Maverick IIR, two test sites were used but were not employed at the same time, so we classified the program as having only one test site.

Table III-3. IOT&E Dummy Variable Values

Program	Test Phase	IOT&E Dummy Variable
AMRAAM	DT&E/IOT&E	0.50
Maverick IIR	DT&E/IOT&E	0.46
SRAM	Cat I/Cat II	0.42
Harpoon	CTE/NTE	0.45

The weighted non-linear least squares regression results were generally consistent with expectations. In our specification, months per launch (M/L) is a function of guidance weight, number of test sites (NSITES), dummy variables for test environment and mission effects (Interceptor, BMD, SUR), and test phase (Pre-EMD and IOT&E, where DT&E is the base case). The resulting equation is:

$$M/L = .389\ (\text{Guidance Weight})^{.239}\ (\text{NSITES})^{-.621} (Qm_i)^{-.155}\ 1.886^{(\text{Interceptor})}\ 2.375^{(\text{BMD})}\ .519^{(\text{SUR})}\ 2.025^{(\text{Pre-EMD})}\ .741^{(\text{IOT\&E})}$$

$$(.01) \quad (.01) \quad (.03) \quad (.01) \quad (.01) \quad (.01) \quad (.01) \quad (.03)$$

$N = 55$ $\quad R^2 = .87$ $\quad$ Adjusted $R^2 = .81$ $\quad \hat{\sigma}^2 = 1.88$ $\quad \hat{\sigma}_i = (1.88/N_i)^{.5}$

The signs of the coefficients are intuitively correct. All coefficients are significant at the .03 level or better. M/L increases with guidance weight and decreases at a decreasing rate with the number of concurrent test sites employed. The coefficient on the progress function variable, Qm_i, indicates an 90% progress rate. The ordering of rate effects for the test phases is as expected with rates increasing for phases later in the program.

Given the estimation procedure used, the interpretation of the goodness-of-fit statistics is different than for the previous regression equations. As explained earlier, the variance and standard error of the estimate terms differ depending upon the number of launches in the test phase, where Var $[\varepsilon_i] = \sigma_i^2 = \sigma^2(1/N_i)$. Given this and the estimate of $\sigma^2 = 1.88$, we can estimate the standard error of the estimate for any N_i. For example, at the mean of N_i for our sample, 20, $\hat{\sigma}_i = [1.88/20]^{.5} = .31$. As the error terms are additive in this model, $\hat{\sigma}_i$ is in the original dimension of the dependent variable. Figure III-3 plots actual months-per-launch predicted by the above equation against model estimates.

Notable outliers include the Sparrow M CTE, Maverick EO Category II (overestimated), Stinger GTV, SM-2 DT Spartan OT and PATRIOT MM (underestimated). The PATRIOT MM and ERINT-1 appear to be overly influential data points. However, we find that when we re-estimate the regression with the two data points excluded, the parameter estimates change very little. The fitted values for PATRIOT MM and ERINT-1 change from 5.41 to 4.16 and 4.28 to 3.47, respectively, when we apply the re-estimated model to those programs. This is an impressive performance given that the two data points are far outside the range of the remaining data.

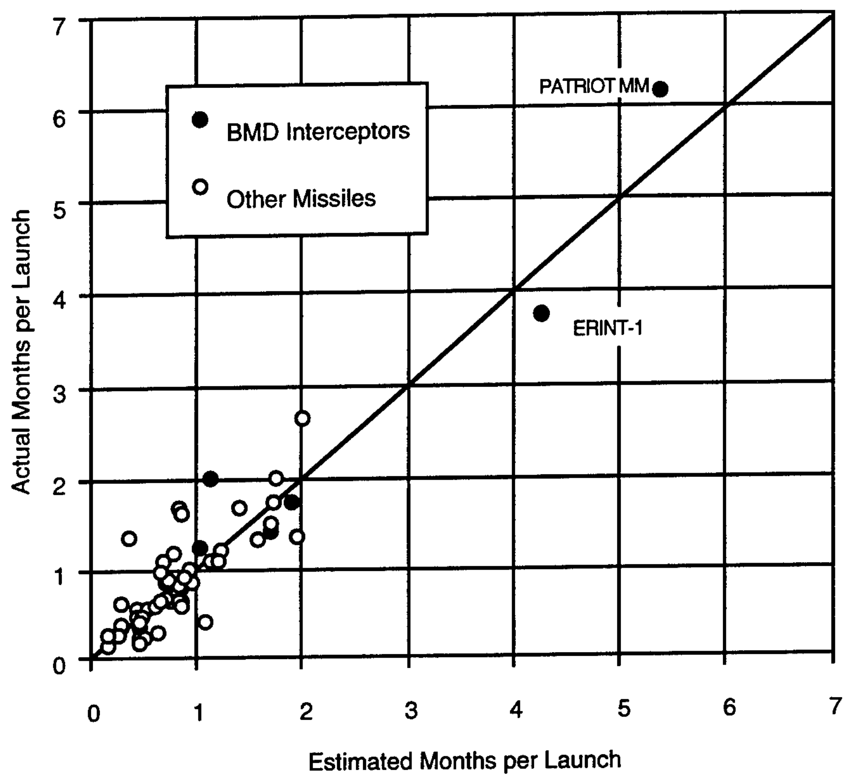

Figure III-3. Predicted Versus Actual Months per Launch: Full-Sample TER

Table III-4 summarizes the prediction errors associated with fitting the equation to the data.

The coefficient of .519 on the SUR dummy shows that there is a large difference in the constant terms between the TER as applied to surface-launched missiles and air-launched missiles. Another question to answer is this: are there differences in the slopes and the effects of the other dummy variables? We decided to answer this question by estimating separate TERs for each type of missile.

Table III-4. Prediction Error Summary for Months per Launch: Full-Sample TER

Program	Phase	Actual Months/Launch	Fitted Value	Error	Relative Error
IHAWK	R&D	0.58	0.90	-0.31	0.65
	Engineering Test	0.66	0.73	-0.07	0.90
	CORE Test Program	0.45	0.52	-0.07	0.86
	PD/IP/IOTE	0.40	0.48	-0.08	0.84
PATRIOT	Proof of Principle and Evaluation	0.90	0.93	-0.03	0.97
	Phase II Engineering Test	0.85	0.77	0.09	1.12
	Phase III Engineering Test	0.97	0.69	0.28	1.40
	OT	0.21	0.48	-0.27	0.43
	DT	0.56	0.63	-0.07	0.89
SM-2	DT	1.62	0.89	0.73	1.82
	OTE	0.22	0.54	-0.32	0.41
	DT-III	0.62	0.68	-0.06	0.91
	OT-III	0.16	0.49	-0.33	0.32
Stinger	GTV	1.33	0.40	0.93	3.34
	Design	0.36	0.32	0.04	1.11
	Prototype Qual (Contractor)	0.26	0.29	-0.03	0.90
	Prototype Qual/OTII	0.13	0.19	-0.06	0.69
	Production Prototype Test	0.24	0.18	0.05	1.29
Sprint	DT	1.39	1.73	-0.34	0.80
	OT	1.23	1.04	0.19	1.18
Spartan	DT	1.71	1.93	-0.22	0.89
	OT	2.00	1.15	0.85	1.75
PATRIOT MM	Pre-EMD	6.17	5.41	0.76	1.14
ERINT-1	Pre-EMD	3.74	4.28	-0.54	0.87
Sparrow F	CDT	1.30	1.63	-0.33	0.80
	NTE	0.63	0.87	-0.24	0.72
	OPEVAL I	0.33	0.49	-0.16	0.67
	OPEVAL II	0.54	0.46	0.08	1.17
Sparrow M	CTE	0.40	1.11	-0.70	0.36
	JTE	0.28	0.65	-0.37	0.44
Sidewinder L	Pre-EMD	1.49	1.72	-0.23	0.87
	CTE	0.78	0.87	-0.10	0.89
	JTE/OPEVAL/IOT&E	0.33	0.31	0.02	1.06
Sidewinder M	CTE	1.67	0.86	0.81	1.94
Phoenix A	CDT (EMD)	1.72	1.75	-0.02	0.99
	CDT (TP/VE)	1.67	1.40	0.27	1.19
	NTE	0.85	0.98	-0.13	0.87
	OPEVAL	0.99	0.94	0.05	1.06
Phoenix C	CTE	2.63	2.04	0.59	1.29
	NTE	1.20	1.26	-0.06	0.95
	OPEVAL	1.08	1.15	-0.08	0.93

Table III-4. Prediction Error Summary for Months per Launch: Full-Sample TER (continued)

Program	Phase	Actual Months/Launch	Fitted Value	Error	Relative Error
AMRAAM	DT&E/IOT&E	0.55	0.55	0.00	1.00
Maverick EO	Cat I	0.81	0.86	-0.05	0.94
	Cat II	0.19	0.49	-0.30	0.39
Maverick IIR	DT&E/IOT&E	0.84	0.73	0.11	1.15
SRAM	Cat I/Cat II	0.63	0.78	-0.15	0.80
Harpoon	Pre-EMD	1.06	1.22	-0.16	0.87
	CTE/NTE	0.47	0.46	0.00	1.01
	OPEVAL	0.60	0.31	0.28	1.89
ALCM	Pre-EMD	1.35	1.98	-0.63	0.68
	DT&E	0.63	0.85	-0.22	0.74
	DT&E (follow-on)	1.09	0.69	0.40	1.57
HARM	Pre-EMD	2.00	1.77	0.23	1.13
	CTE	1.18	0.80	0.37	1.47
	NTE/OPEVAL/IOT&E	0.36	0.30	0.06	1.20

In estimating a surface-launched missile TER, we did not have to include the Interceptor dummy variable as all surface-launched missiles in our database were interceptors. Also, only two pre-EMD programs and no multiple-test-site cases were in the surface-launched data subset. We found that the progress curve effect overwhelmed the pre-EMD and IOT&E effects for the surface-launched data subset. The resulting equation is:

$$M/L = 1.494\ (\text{Guidance Weight})^{.097}(Qm_i)^{-.420}\ 2.243^{(BMD)}$$

(.38) (.01) (.01)

$N = 24$ $R^2 = .84$ Adjusted $R^2 = .81$ $\hat{\sigma}^2$=2.86 $\hat{\sigma}_i = (2.86/N_i)^{.5}$

Although Guidance Weight is only significant at the .38 level, we chose to include it because it has proved to be an important variable in all our other TERs. The coefficient on the Qm_i variable indicates a 75% progress curve for months per launch. As the pre-EMD and IOT&E variables were not in the equation, the steeper progress curve when compared with the full-sample TER was expected. The value of the BMD dummy variable is comparable to its value for the full-sample TER.

Figure III-4 plots actual months per launch predicted by the above equation against model estimates. Table III-5 summarizes the prediction errors associated with fitting the equation to the data.

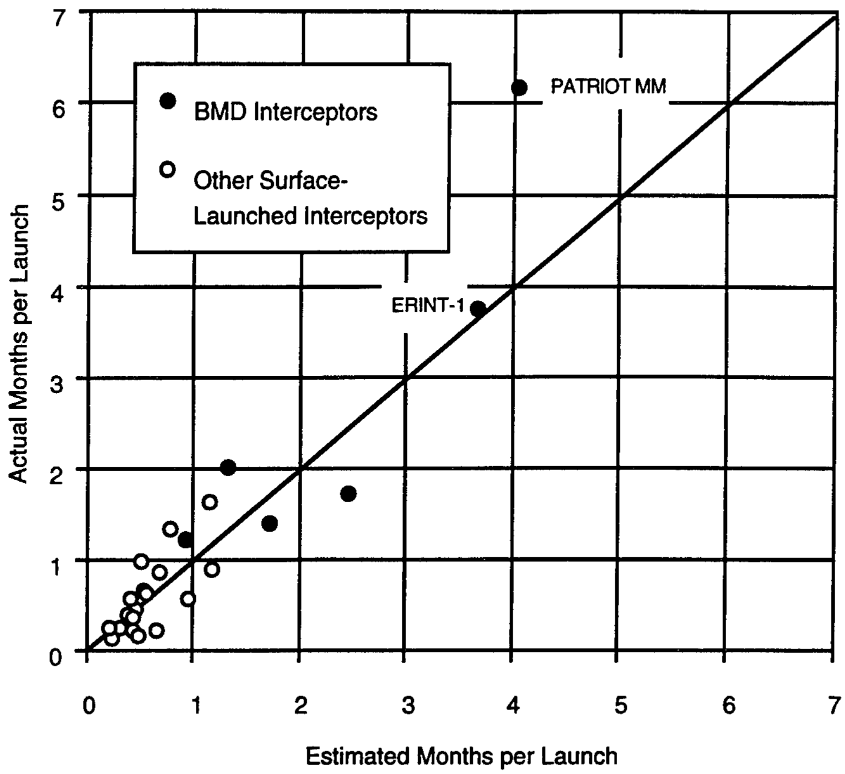

Figure III-4. Predicted Versus Actual Months per Launch: Surface-Launched Missile TER

The results show the model performing better than the full sample model for non-BMD interceptors. For example, The Stinger GTV test phase is now a much smaller outlier. Unfortunately, the model's performance is worse for BMD interceptors, and the overall measures of model fit are poorer.

The next step was to estimate a months-per-launch TER for air-launched missiles only. This TER more closely resembles the full-sample TER. However, it excludes the BMD variable because there are no air-launched ballistic missile interceptors. The SUR variable remains, as the data subset includes two test programs that had surface launches in addition to air launches. The resulting equation is:

$$M/L = .431\,(\text{Guidance Weight})^{.184}_{(.01)}\,(\text{NSITES})^{-.636}_{(.03)}\,\underset{(.01)}{1.633}^{(\text{Interceptor})}\,\underset{(.01)}{.303}^{(\text{SUR})}\,\underset{(.01)}{1.806}^{(\text{Pre-EMD})}\,\underset{(.01)}{.480}^{(\text{IOT\&E})}$$

$N = 31$ $\quad R^2 = .76$ $\quad$ Adjusted $R^2 = .70$ $\quad \hat{\sigma}^2 = 1.23$ $\quad \hat{\sigma}_i = (1.23/N_i)^{.5}$

Table III-5. Prediction Error Summary for Months per Launch: Surface-Launched Missile TER

Program	Phase	Actual Months/Launch	Fitted Value	Residual	Relative Error
IHAWK	R&D	0.58	1.00	-0.42	0.58
	Engineering Test	0.66	0.57	0.10	1.17
	CORE Test Program	0.45	0.49	-0.04	0.91
	PD/IP/IOTE	0.40	0.40	0.00	1.01
PATRIOT	POP & EVAL	0.90	1.21	-0.31	0.74
	Phase II Engineering Test	0.85	0.71	0.14	1.20
	Phase III Engineering Test	0.97	0.54	0.43	1.79
	OT	0.21	0.45	-0.24	0.46
	DT	0.56	0.43	0.13	1.31
SM-2	DT	1.62	1.19	0.43	1.36
	OTE	0.22	0.69	-0.46	0.32
	DT-III	0.62	0.58	0.04	1.08
	OT-III	0.16	0.52	-0.36	0.31
Stinger	GTV	1.33	0.82	0.51	1.63
	Design	0.36	0.44	-0.09	0.80
	Prototype Qual (Contractor)	0.26	0.33	-0.07	0.78
	Prototype Qual/OTII	0.13	0.26	-0.12	0.52
	Production Prototype Test	0.24	0.22	0.01	1.06
Sprint	DT	1.39	1.73	-0.34	0.80
	OT	1.23	0.94	0.29	1.31
Spartan	DT	1.71	2.49	-0.78	0.69
	OT	2.00	1.32	0.68	1.51
PATRIOT MM	Pre-EMD	6.17	4.09	2.08	1.51
ERINT-1	Pre-EMD	3.74	3.71	0.02	1.01

Parameter estimates are similar to those for the full-sample TER. The progress curve variable was not statistically significant and was excluded from the equation. This results in a larger effect for the IOT&E variable. Estimating error improves with $\hat{\sigma}^2$ decreasing from 1.88 to 1.23. Figure III-5 plots actual months-per-launch predicted by the above equation against model estimates.

Table III-6 summarizes the prediction errors associated with fitting the equation to the data on the surface-launched TER.

Given the results of our analyses we can make a few observations about missile flight test schedules and their estimation. For the primary object of our concern, surface-launched ballistic missile interceptor programs, the best TER appears to be the one derived from the full data sample. For other surface-launched interceptors, the surface-launched missile TER best fits the data, while for air-launched interceptors, the air-launched missile TER is superior.

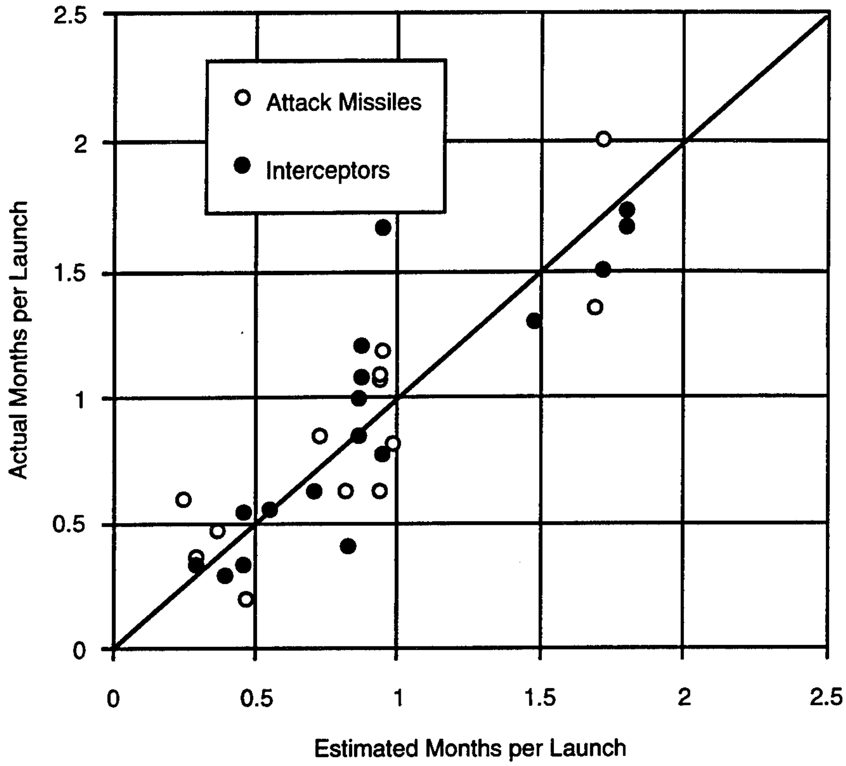

Figure III-5. Predicted Versus Actual Months per Launch: Air-Launched Missile TER

Table III-6. Prediction Error Summary for Months per Launch: Air-Launched Missile TER

Program	Phase	Actual Months/Launch	Fitted Value	Residual	Relative Error
Sparrow F	CDT	1.30	1.49	-0.19	0.87
	NTE	0.63	0.71	-0.08	0.88
	OPEVAL I	0.33	0.46	-0.13	0.71
	OPEVAL II	0.54	0.46	0.08	1.18
Sparrow M	CTE	0.40	0.83	-0.43	0.49
	JTE	0.28	0.40	-0.11	0.71
Sidewinder L	Pre-EMD	1.49	1.72	-0.23	0.87
	CTE	0.78	0.95	-0.18	0.81
	JTE/OPEVAL/IOT&E	0.33	0.29	0.03	1.11
Sidewinder M	CTE	1.67	0.95	0.71	1.75
Phoenix A	CDT (EMD)	1.72	1.81	-0.09	0.95
	CDT (TP/VE)	1.67	1.81	-0.14	0.92
	NTE	0.85	0.87	-0.02	0.98
	OPEVAL	0.99	0.87	0.12	1.14
Phoenix C	CTE	2.63	1.83	0.80	1.43
	NTE	1.20	0.88	0.32	1.37
	OPEVAL	1.08	0.88	0.20	1.22
AMRAAM	DT&E/IOT&E	0.55	0.56	-0.01	0.98
Maverick EO	Cat I	0.81	0.99	-0.17	0.82
	Cat II	0.19	0.47	-0.28	0.41
Maverick IIR	DT&E/IOT&E	0.84	0.73	0.11	1.15
SRAM	Cat I/Cat II	0.63	0.82	-0.19	0.76
Harpoon	Pre-EMD	1.06	0.94	0.13	1.13
	CTE/NTE	0.47	0.37	0.09	1.25
	OPEVAL	0.60	0.25	0.35	2.39
ALCM	Pre-EMD	1.35	1.69	-0.34	0.80
	DT&E	0.63	0.94	-0.31	0.67
	DT&E (follow-on)	1.09	0.94	0.15	1.16
HARM	Pre-EMD	2.00	1.72	0.28	1.16
	CTE	1.18	0.95	0.22	1.23
	NTE/OPEVAL/IOT&E	0.36	0.29	0.06	1.22

In addition to estimates of months per launch, estimates of the number of missiles to be launched and their distribution across test phases are needed in order to estimate test program lengths. The number of launches required to test a missile's readiness for production and deployment is based on engineering analyses made prior to the start of EMD. Sometimes, the estimates are raised or lowered in the course of development. For example, the number of test launches for the Sparrow F increased from the original plan because of technical problems, and the number of launches for the AIM-65D were decreased because of funding constraints. Examination of the number of test launches by EMD program reveals certain patterns.

The programs with the greatest number of launches (excluding the Hellfire) were the interceptor developments, excluding BMD interceptors. The non-BMD interceptor missile developments that were new starts, the PATRIOT, Stinger, Phoenix A and AMRAAM, had 62, 112 (excluding 18 Production Prototype), 85 and 91 launches, respectively. The BMD missiles with completed EMD programs, the Sprint and Spartan, had fewer launches, 76 and 35, respectively. Total launches for new tactical air-to-surface missile developments (again excluding the Hellfire) fell within a narrow range: 52 launches for the Maverick EO, 58 launches for the HARM, and 66 launches for the Harpoon. The Hellfire, which had 169 launches, is a conspicuous outlier. This large number of launches may be a result of the low unit cost of the Hellfire when compared with the other missiles. For most programs, the high unit cost of test assets requires that the number of launches be minimized given the amount of information needed to be gathered. The two strategic systems, the SRAM and ALCM had fewer test launches than the tactical systems with 38 and 21 launches each. The strategic systems made use of fewer types of launch platforms during testing than the other air-to-surface systems.

Modification programs had more variability with total EMD launches varying from 31 launches for the Phoenix C to 99 for the IHAWK and Sparrow F. For most modification programs, the number of test launches was considerably lower than was the case with comparable new programs. Exceptions were the Sparrow F, IHAWK, and the Sidewinder L (60 launches). These missiles incorporated changes beyond modified guidance systems with major alterations in airframe (IHAWK, Sparrow F, and Sidewinder L) and propulsion (IHAWK, Sidewinder F) systems. The Sparrow F was also unusual in that unsatisfactory results during OPEVAL lead to the re-running of that 25-missile test phase. Modified missiles that did not have major changes to the missile's airframe and propulsion were the subject of fewer test firings, as evidenced by the Phoenix C (31 launches) and the Maverick IIR (26 launches).

For air-launched missiles there seems to be a relationship between the number of types of launch platforms used during testing and the number of test launches. As the number of platform types increases, the number of test launches should also increase—an important aspect of testing is the integration of the missile with the platform's fire-control system and airframe.

Contractor representatives noted a decrease in the number of test launches required for more modern programs because of improved computer simulation. Although this trend is not obvious on inspection of the data, it is testable by including a time-trend variable in the regression equation.

Given these observations, we estimated an equation to be used to check engineering estimates of the total number of test missiles launched in EMD through IOT&E (NMISS). In order to account for the regularities discussed previously, we regressed the total number of test launches against 1/0 indicator variables identifying interceptor missile programs (Interceptor), ballistic missile defense programs (BMD) and modification programs (MOD), a variable for the number of types of launch platforms used in EMD (NPLATFORM), a time-trend variable, and a variable to account for the unit procurement cost of the missiles. For the time trend variable the index used is the year EMD began minus 1962 (EMDyr-1962), which marks the start of the oldest program in our sample. For the unit procurement cost variable, we used the 1000th unit procurement cost in thousands of FY90 dollars (PUC_{1000}) as estimated by a top-level cost-estimating relationship (CER) presented in Appendix D. Using an estimate from a CER has two advantages over using actual historical costs. The first is that historical unit cost data will not be available for future programs; secondly, such a variable would be a stochastic regressor, the use of which would cause econometric problems.

In specifying the functional form it was decided that a multiplicative form would best capture all of the effects except for the platform (NPLATFORM) effects. It is likely that the effect of adding more platform types to a test program would be linear and additive. Because of the resulting specification, we were forced to employ non-linear least squares to estimate the NMIS relationship where the error terms are also treated as additive. The resulting equation is:

$$\underset{}{NMIS} = 192.2\, \underset{(.01)}{(PUC_{1000})^{-.226}}\, \underset{(.17)}{2.357^{(Interceptor)}}\, \underset{(.03)}{.600^{(BMD)}}\, \underset{(.02)}{.657^{(MOD)}}\, \underset{(.07)}{.965^{(EMDyr-1962)}} + \underset{(.14)}{5.715\,(NPLATFORM)}$$

$N = 17 \qquad R^2 = .72 \qquad \text{Adjusted } R^2 = .56 \qquad \hat{\sigma} = 18.7$

Data points not in the equation are the Sparrow M, the Sidewinder M, and the Hellfire. Complete data on the Sparrow M and the Sidewinder M were not available. Even with the unit cost variable included, the Hellfire was a conspicuous outlier.

The signs of the coefficients are intuitively correct. The interpretation on the parameter estimate for PUC_{1000} is that the more expensive the test missiles being launched, the more resources the program managers will apply to each launch. This will increase the amount of information gained from each launch and decrease the total number of launches required. The higher complexity and more diverse test scenarios associated with interceptor missiles would explain the coefficient on the Interceptor variable. BMD interceptor testing should present fewer scenarios than for testing involving air-breathing targets. Modified missiles should require less testing because significant portions of the missile's performance should already be well understood. The coefficient on the time trend variable indicates a 3.5% decrease in missile launches required for each calendar year. This is consistent with the development and wider employment of simulation and other technologies enabling fewer test launches. The coefficient on the platform variable indicates that integrating a missile on an additional platform type should require on average 5.7 additional launches.

Figure III-6 plots actual months per launch predicted by the above equation against model estimates. Table III-7 summarizes the prediction errors associated with fitting the equation to the data.

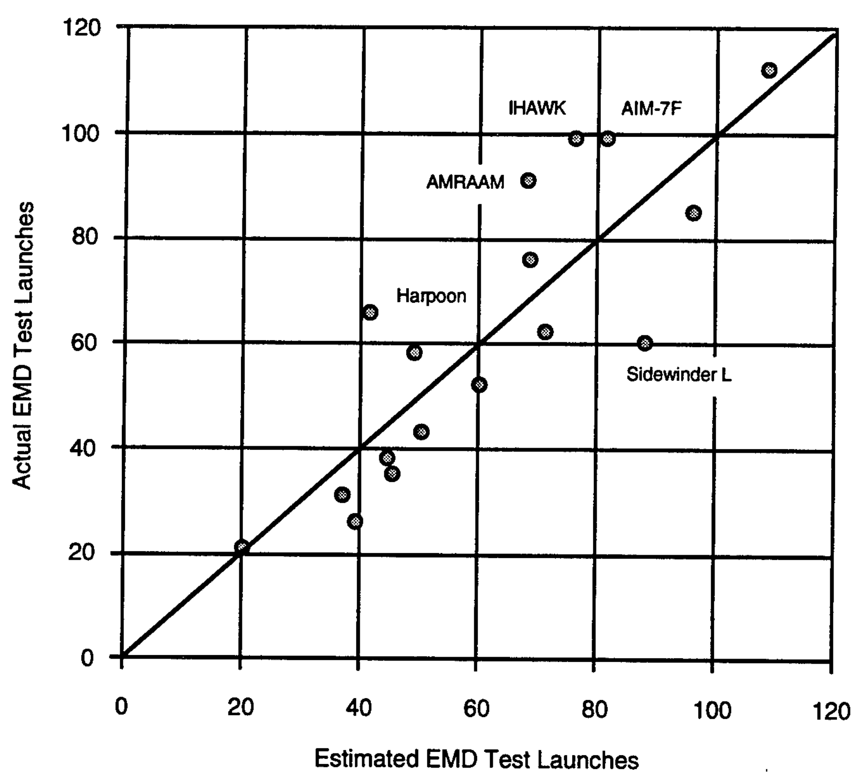

Figure III-6. Predicted Versus Actual Number of EMD Test Launches

Table III-7. Prediction Error Summary: EMD Test Launch Relationship

Program	Actual Value (Launches)	Predicted Value (Launches)	Error (Actual – Predicted)	Multiplicative Error (Actual/Predicted)
IHAWK	99	77.0	22.0	1.29
PATRIOT	62	71.9	-9.9	0.86
SM-2	43	50.7	-7.7	0.85
Stinger	112	109.1	2.9	1.03
Sprint	76	69.1	6.9	1.10
Spartan	35	45.8	-10.8	0.76
Sparrow F	99	82.6	16.4	1.20
Sidewinder L	60	88.5	-28.5	0.68
Phoenix A	88	98.9	-10.9	0.89
Phoenix C	31	37.0	-6.0	0.84
AMRAAM	91	68.8	22.2	1.32
Maverick EO	52	60.4	-8.4	0.86
Maverick IIR	26	39.8	-13.8	0.65
SRAM	38	45.1	-7.1	0.84
Harpoon	66	42.3	23.7	1.56
ALCM	21	20.4	0.6	1.03
HARM	58	49.4	8.6	1.17

D. EARLY PRODUCTION

In our analysis of early production data, the emphasis was on both the production times for the early procurement lots and the concurrency between production and development. Production times are as defined in Section II: the time from production-lot long-lead and full-funding release to the first lot delivery for the early production lots. We characterize concurrency by looking at the progress of the flight-test program in relation to production long-lead and full-funding milestones.

In general we found no statistical relationships between missile or program characteristics and production times. The one exception was a statistically significant difference in the mean times between the Army and Air Force/Navy programs for the full funding to first delivery milestone. The difference was significantly different than zero at the .01 level (two tail) using a two-sample t-test assuming unequal variances.

Fortunately, there is little variability in the two intervals, particularly for the long-lead interval. Because of this lack of variability, we think that simple descriptive statistics adequately characterize production times. Descriptive statistics for both production intervals are presented in Table III-8. Note that the data exclude the estimated values previously presented.

Table III-8. Descriptive Statistics for Production Times

Sample	Long Lead to First Production	Contract Award to First Production
Total Sample		
Mean (months)	24.0	17.4
Standard Error (months)	3.7	5.2
Sample Size	26	38
Army		
Mean (months)	25.4	20.3
Standard Error (months)	2.6	3.3
Sample Size	5	11
Navy and Air Force		
Mean (months)	23.6	16.2
Standard Error (months)	3.8	5.4
Sample Size	21	27

In developing alternative measures of concurrency, we looked beyond the time interval measures presented in Table II-12 and examined the actual progress of the flight test program in relation to both long-lead (LL) and full-funding (FF) release. Table III-9 lists the number of missile launches accomplished at the two production milestones and the percentage of total program launches they represented. Estimated values are based on estimated long-lead intervals as identified in Table II-12.

Table III-9. Measures of Concurrency

First Production Lot	Launches at LL	Launches at FF	Total Launches	Percent at LL	Percent at FF
IHAWK FY70 Production	41[a]	51	99	41[a]	52
PATRIOT FY80 Production	56	62	62	90	100
Stinger Low Rate Production	112	112	112	100	100
SM2 Blk I Pilot Production	6[a]	10	43	14[a]	23
Spartan First Production	16	18	35	46	51
Sparrow F FY75 Production	86[a]	99	99	87[a]	100
Sidewinder L FY76 Production	60	60	60	100	100
Phoenix A FY72 Production	33	49	85	39	58
Phoenix C FY80 Production	0	0	21	0	0
AMRAAM FY86 Production	19	43	91	21	47
Maverick EO Option A Production	11[a]	41	52	21[a]	79
Maverick IIR FY82 Production	16	26	26	62	100
SRAM First Production	10	28	38	26	78
Harpoon First Production	29	39	66	44	59
ALCM FY80 Production	4	10	31	19	48
HARM First Production	19	25	58	33	43

[a] Estimates.

The measures lead to somewhat different conclusions about the relative concurrency of the programs when compared with the simple interval overlap measures presented in Table II-14. The Phoenix A was a highly concurrent outlier according to the interval measures. When looking at the percentage measures above, it emerges as a program of average concurrency. The high months per launch and very long test period for the Phoenix A program meant that even at over 50 months prior to test end, over half of total launches had been completed. A similar, although more moderate effect is evident for the Spartan. The Phoenix C remains an outlier; the two production milestones occurred before the first launch. The SM-2 looked only moderately concurrent in Table II-14 with test end occurring only 13 months after the full-funding release; however, with the new measures, it looks quite concurrent with only 23% of the EMD launches completed at full funding.

Five of the six programs that were unambiguously non-concurrent according to the interval measures also show as non-concurrent programs here. The exception is the Maverick EO. Although the estimated long-lead release date preceded the end of Maverick EO Category II testing by only seven months, 36 launches were completed in that period owing to the very high launch-rate achieved in Category II testing. The two programs with divergent measures of concurrency at long-lead and full-funding release, the Maverick EO and SRAM, are characterized by widely differing months per launch at the beginning and end of their test programs.

According to both percentage measures, four of the programs (excluding the Phoenix C) are shown to be the most concurrent, the SM-2, AMRAAM, the ALCM, and the HARM. The missiles developed during these programs had unique capabilities not approximated in inventory missiles. Although the SM-2 was a modification program, its capabilities were required by the new AEGIS fire-control system. Conversely, missiles developed during the least concurrent programs, the Sparrow F and Sidewinder L, were incremental improvements to existing systems. The implication is that policy makers are willing to incur a higher degree of concurrency risk in order to more quickly field a system with a unique capability.

E. PROGRAM LENGTH FROM FIRST LAUNCH

We would have preferred to estimate total program length (defined as the time from EMD start to the delivery of the first production missile) to be used as an aggregate check on estimates derived for the other schedule intervals. Unfortunately, the determinants of time to first launch and time from first launch to first production are just too different. According to our regression work, time to first launch is a function of technological variables. Time from first launch to first production is a function of the number of missiles launched in flight test, the rate at which they are launched, the overlap between production start and flight test, and production time. The number of test launches is unrelated to time to first launch even in a coincidental fashion.

In order to estimate a correctly specified equation for the number of months from first launch to first production delivery (FL_FDEL), we were forced to employ nonlinear least-squares regression. We characterized both flight test length and its concurrency with production by using the number of flight test missiles launched at long-lead release (NMISLL) as an independent variable. This variable interacts multiplicatively with missile characteristic variables that are determinants of launch rate. As production time has no variability related to any of these factors, it is best characterized by an additive intercept. The combination of an additive intercept with the multiplicative terms describing flight test length requires that we estimate the equation using nonlinear least squares with additive errors. The resulting equation and measures of model fit are:

$$FL\_FDEL = \underset{(.01)}{27.4} + .250\ (\text{Guidance Weight})^{\underset{(.01)}{.227}}\ (NMISLL)^{\underset{(.01)}{.856}}\ \underset{(.02)}{2.480}^{(\text{Interceptor})}\ \underset{(.07)}{1.956}^{(BMD)}\ \underset{(.18)}{.848}^{(SUR)}$$

$$N = 17 \qquad R^2 = .90 \qquad \text{Adjusted } R^2 = .83 \qquad \hat{\sigma} = 9.0$$

The parameter estimates are mostly consistent with expectations. The additive intercept is close to the average time period from long-lead release to first production delivery (24 months). The decrease in months per launch as the test program progresses is indicated by the parameter estimate of less than one on the NMISLL variable. We expected that the interval would increase with guidance weight and be longer for interceptor and BMD interceptor programs and shorter for surface-launched programs. One surprise is the coefficient on the SUR variable, .848, which is only significantly different than 1 at the 0.18 level. In the months-per-launch equation, the coefficients on SUR were close to 0.5 and highly significant. Figure III-7 plots actual months per launch predicted by the above equation against model estimates.

The equation estimating program length from first launch has at least two uses. First, it can provide a quick method of assessing the total length of proposed EMD programs given an estimate of time to first guided launch. The other and, perhaps, more interesting use is that of a consistency check on schedule estimates produced from an integrated set of the interval estimates addressed in the previous sections of this chapter. Model application is the subject of the next chapter.

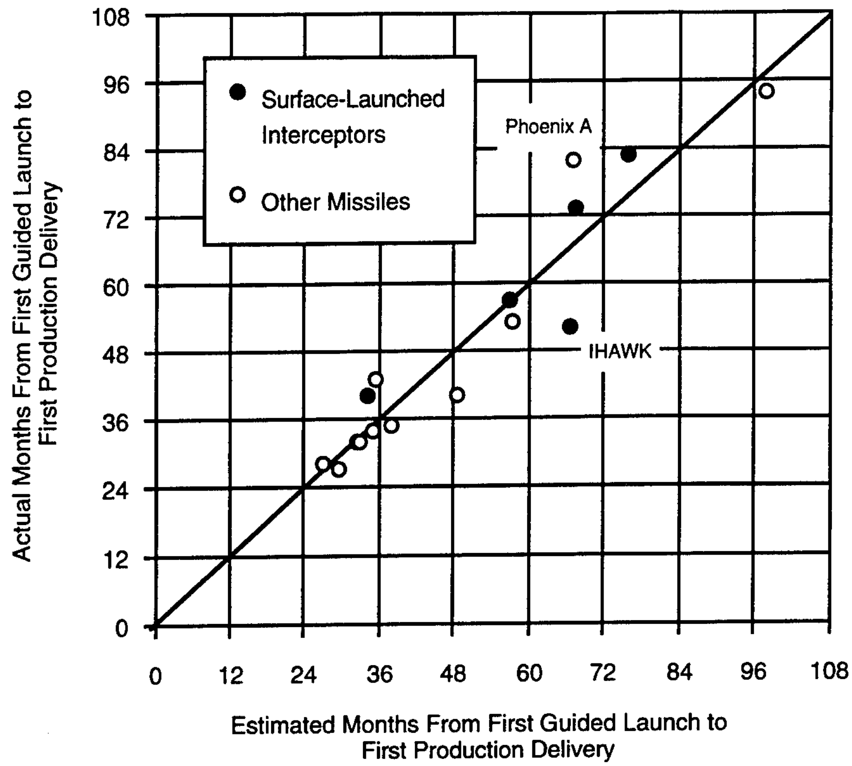

Figure III-7. Predicted Versus Actual Time to First Production

Table III-10 summarizes the prediction errors from the regression.

Table III-10. Prediction Error Summary: Time to First Production TER

Program	Actual Value (Months)	Predicted Value (Months)	Error (Actual – Predicted)	Multiplicative Error (Actual/Predicted)
HAWK	52	66.6	-14.6	0.78
PATRIOT	83	76.1	6.9	1.09
SM-2	40	34.3	5.7	1.17
Stinger	73	67.7	5.3	1.08
Spartan	57	57.0	.0	1.00
Sparrow F	94	98.1	-4.1	0.96
Sidewinder L	53	57.4	-4.4	0.92
Phoenix A	82	67.1	14.9	1.22
Phoenix C	28	27.4	.6	1.02
AMRAAM	40	48.8	-8.8	0.82
Maverick EO	32	32.8	-.8	0.98
Maverick IIR	34	35.2	-1.2	0.97
SRAM	32	33.2	-1.2	0.96
Harpoon	35	38.2	-3.2	0.92
ALCM	27	29.5	-2.5	0.92
HARM	43	35.7	7.3	1.21

IV. MODEL INTEGRATION AND APPLICATION

A. INTEGRATION

In Chapter III, we analyzed four schedule intervals related to engineering and manufacturing development. The task now is to fit these analyses together so that a consistent and useful model results. To do this, the way in which the intervals relate to one another must be defined. The concurrency of development and early production then becomes an issue of particular concern.

The relationship between first guided launch and the development flight test program is obvious and poses no problem—flight testing begins at the first guided launch of a development missile. If the completion of initial operational testing is considered to be the same as completion of EMD, a total program estimate is easily made by adding the estimates for these two intervals together. However, our model does not define total development length this way. The end of development is tied to the delivery of the first production missile. The flight test interval is not directly linked to early production. What actually ties development and production schedules together is what is often called concurrency.

Concurrency was defined in general terms as the overlap of development and production. To quantify this overlap, the definition must be narrowed. Defining concurrency more specifically poses a problem. The trouble lies in identifying which development and production activities are most important in their relationship to one another. In our examination of production data (Chapter III), we put forth the following measure of concurrency: the number of missile launches accomplished at long-lead release for the first production lot. This definition stresses the importance of flight testing as a determinant of the completeness of development. It also favors the start of production activity (as defined by long-lead release), rather than the start of production deliveries, as the best indicator of the status of production.

The degree of overlap between the test program and early production is considered a decision variable arrived at outside of the model. Past experience, however, can help define what are reasonable degrees of concurrency. Given values for this exogenous factor and estimates for time to first guided launch, number of test launches, launch rate, and production times, the length of the total EMD program can be estimated. Once such an estimate is made, the equation for program length from first launch can be used to check for consistency.

B. APPLICATION

The application of the model sketched out in the previous subsection can be approached in two ways. The easiest approach is to use the model in its role as an assessment tool. Once the relevant intervals are identified in a proposed schedule, comparisons can be made using the intervals estimated from the equations described in Chapter III. The probability of achieving the interval can be calculated given the information provided in the analyses. The more difficult approach is to generate an estimated schedule where no proposed schedule exists. The statistical properties of the models can be used to produce the expected value of intervals, as well as intervals associated with various probabilities of success. Although the first approach is more attuned to the goals of this research, the second approach will illuminate the important aspects of both types of applications. We took the latter approach to generate the example missile schedule presented here.

Before applying the model, some assumptions must be made about the hypothetical program. Simulating a flight test program with estimated launch rates requires that the number of test launches and the distribution of those launches over test phases be specified. We can estimate the total number of EMD test launches using the relationship provided in Chapter III. Another problem is in deciding upon the degree of concurrency (i.e., when the long-lead release date will be in relationship to the progress of the flight test program). Values also need to be assumed for the independent variables of the regression equation.

Our hypothetical missile, the BMD-Ø, is a surface-launched ballistic missile interceptor beginning development in 1995. Its guidance system weighs 70 pounds, is packaged in a 1,750-cubic-inch guidance section, and requires 2,500 watts of power. This results in a relatively high measure of power density of 1.43 watts per cubic inch. Average unit procurement cost at 1,000 missiles is estimated at $1 million in FY90 dollars. The test program will consist of launches split evenly between DT&E and IOT&E phases. Go-ahead for long-lead release will be given after the completion of DT&E. With long-lead release occurring with 50% of EMD launches completed, this gives the BMD-Ø an average amount of concurrency in relation to the rest of our sample. Table IV-1 lists the BMD-Ø missile and program characteristics.

Table IV-1. BMD-Ø Surface-Based Interceptor Missile and Program Characteristics

Year of EMD Start	1995
Guidance Weight	70 lbs.
Power Density	1.43 watts/in.^{3}
Estimated Average Cost for 1,000 missiles, PUC_{1000} (thousands of FY90 dollars)	$1,000
Distribution of Flight Test Launches:	
DT&E	50%
IOT&E	50%
EMD Launches at Long-Lead Release	50%

When estimating the BMD-Ø's schedule, we estimated the expected value of the schedule, based on the expected values of the schedule intervals calculated from the estimating relationships. We assumed that all of the independent variables are non-stochastic. Given that most of the variability explained by the models is attributable to the 1/0 dummy variables, this is a reasonable assumption. We also assumed that all of the estimated values were independent. For each interval estimated, we chose the TER that we felt was most appropriate to the problem at hand.

For time to first guided flight, we chose the augmented estimating relationship:

$$\text{TFGL} = 6.889\ \underset{(.01)}{(\text{Guidance Weight})^{.318}}\ \underset{(.01)}{(\text{Power Density})^{.172}}\ \underset{(.02)}{1.330^{(\text{Interceptor Dummy})}}$$

$N = 16$ $R^2 = .88$ Adjusted $R^2 = .85$ $\hat{\sigma} = .177$ $\hat{\sigma}' = 4.2$ Intercept adjustment = 1.016

We chose this because of general superiority of the augmented TER and the relatively high power density of the BMD-Ø. The result is:

$$\text{TFGL} = 6.889\ (70)^{.318}\ (1.43)^{.172}\ 1.330^{(1)} = 39.2 \text{ months.}$$

To estimate the length of the EMD flight test program, we first estimated the total number of missiles launched. This was done using the relationship below:

$$\text{NMIS} = 192.2\ \underset{(.01)}{(PUC_{1000})^{-.226}}\ \underset{(.17)}{2.357^{(\text{Interceptor})}}\ \underset{(.03)}{.600^{(\text{BMD})}}\ \underset{(.02)}{.657^{(\text{MOD})}}\ \underset{(.07)}{.965^{(\text{EMDyr-1962})}} + \underset{(.14)}{5.715\ (\text{NPLATFORM})}$$

$N = 17$ $R^2 = .72$ Adjusted $R^2 = .56$ $\hat{\sigma} = 18.7$

Note that this equation was estimated assuming normally distributed additive errors. Using values for the BMD-Ø program, we calculated the expected value for total EMD launches:

$$\text{NMIS} = 192.2\ (1000)^{-.226}\ 2.357^{(1)}\ .600^{(1)}\ .657^{(0)}\ .965^{(1995-1962)} = 23.6 \text{ launches.}$$

We rounded the results to 24 launches. Given the other program assumptions, this means 12 DT&E launches and 12 IOT&E launches, with long-lead release occuring at the completion of DT&E.

In the next step, we used the full-sample TER to estimate the months per launch (M/L) for each of the two test phases:

$$\text{M/L} = .389\ (\text{Guidance Weight})^{\underset{(.01)}{.239}}\ (\text{NSITES})^{\underset{(.01)}{-.621}}\ (Qm_i)^{\underset{(.03)}{-.155}}\ \underset{(.01)}{1.886}^{(\text{Interceptor})}\ \underset{(.01)}{2.375}^{(\text{BMD})}\ \underset{(.01)}{.519}^{(\text{SUR})}\ \underset{(.01)}{2.025}^{(\text{Pre-EMD})}\ \underset{(.03)}{.741}^{(\text{IOT\&E})}$$

$N = 55$ $R^2 = .87$ Adjusted $R^2 = .81$ $\hat{\sigma}^2 = 1.88$ $\hat{\sigma}_i = (1.88/N_i)^{.5}$

In order to calculate the expected value, we first calculated the test phase midpoints for both DT&E and IOT&E using

$$Qm_i = \left\{[(Q_i + .5)^{b+1} - (Q_{i-1} + .5)^{b+1}]/[(Q_i - Q_{i-1})(b+1)]\right\}^{1/b}.$$

For DT&E, we used

$$Qm_i = \left\{[(12 + .5)^{-.155+1} - (0 + .5)^{-.155+1}]/[(12 - 0)(-.155 + 1)]\right\}^{1/-.155} = 5.0 \text{ launches,}$$

while for IOT&E, we used

$$Qm_i = \left\{[(24 + .5)^{-.155+1} - (12 + .5)^{-.155+1}]/[(24 - 12)(-.155+1)]\right\}^{1/-.155} = 18.1 \text{ launches.}$$

Months per launch for DT&E was calculated as

$$\text{M/L} = .389\ (70)^{.239}\ (1)^{-.621}\ (5.0)^{-.155}\ 1.886^{(1)}\ 2.375^{(1)}\ .519^{(1)}\ 2.025^{(0)}\ .741^{(0)} = 1.94,$$

while for 1OT&E it was calculated as

$$\text{M/L} = .389\ (70)^{.239}\ (1)^{-.621}\ (18.1)^{-.155}\ 1.886^{(1)}\ 2.375^{(1)}\ .519^{(1)}\ 2.025^{(0)}\ .741^{(1)} = 1.18.$$

The length of the DT&E test phase was calculated as

$$\text{DT\&E Test Phase Duration} = (12 - 1) \times 1.94 = 21.4 \text{ months.}$$

The length of the IOT&E test phase was calculated as

$$\text{IOT\&E Test Phase Duration} = (12 - 1) \times 1.18 = 13.0 \text{ months.}$$

Neither of the test phase lengths accounts for the period between test phases. The data in Tables II-10 and II-11 show an average duration between test phases of 3.1 months. We used three months when calculating the total test program length.

Table IV-2 lists estimated intervals for the BMD-Ø program. The estimate for production time from long-lead release is the sample average presented in Table III-10.

Table IV-2. BMD-Ø Program Estimated Values

Time to First Guided Launch (months)	39.2
Months Per Launch	
DT&E	1.94
IOT&E	1.18
Test Phase Duration (months)	
DT&E	21.4
IOT&E	13.0
Months Between Test Phases	3.0
Production Time From Long-Lead Release (months)	24.0

Using the estimated intervals and program assumptions, we created a set of estimated program milestones. Table IV-3 provides estimated milestones for the BMD-Ø program expressed in months from EMD start. Here we rounded our estimates to the whole month. The estimated milestone for first production delivery was calculated by adding production time to the long-lead release date, which was, in turn, linked to the completion of DT&E.

Table IV-3. BMD-Ø Program Estimated Milestones

Milestone	Months from EMD Start
First Guided Launch/DT&E Start	39
DT&E End/Production Long Lead Release	61
IOT&E Start	64
IOT&E End	77
First Production Delivery	85

Implied in this estimate is a time from first guided launch to first production delivery of 46 months. In order to provide a check on the above analyses, we applied our more aggregated equation for this interval:

$$FL\_FDEL = 27.4 + \underset{(.01)}{.250} \text{ (Guidance Weight)}^{\underset{(.01)}{.227}} \text{ (NMISLL)}^{\underset{(.01)}{.856}} \ \underset{(.02)}{2.480}^{(\text{Interceptor})} \ \underset{(.07)}{1.956}^{(\text{BMD})} \ \underset{(.18)}{.848}^{(\text{SUR})}$$

$N = 17 \qquad R^2 = .90 \qquad \text{Adjusted } R^2 = .83 \qquad \hat{\sigma} = 9.0$

By including the values for the BMD-Ø program in the equation, we get:

$$FL\_FDEL = 27.4 + .250\ (70)^{.227}\ (12)^{.856}\ 2.480^{(1)}\ 1.956^{(1)}\ .848^{(1)} = 50.1 \text{ months.}$$

The difference in estimates of four months is not surprising. In using the equation for first guided launch to first production, we either ignored or approximated information used to generate the more detailed estimate. Also, this TER was estimated using only a single BMD program, the Spartan, while the other TERs used information from all four BMD programs. If only one method is taken to estimate this interval, it is better that the more detailed approach be used.

There are many more ways the analyses presented in this paper can be applied to schedule assessment problems. The BMD-Ø example is not exhaustive; its main function is to provide a perspective so that BMDO analysts can make better use of the analyses provided.

APPENDIX A

PROGRAM DATA

Table A-1. Improved HAWK Data

Milestones	Dates	Months From EMD Start
Pre-EMD		
Advanced Development Contract Award	6/62	-29
EMD		
EMD Start/EMD Contract Award	11/64	0
EMD Article First Delivery	7/66	20
EMD Article First Launch/CTV	1/66	14
First Guided Launch/DT&E Start	8/67	33
DT&E Complete	7/70	68
IOT&E /Start	1/71	74
IOT&E/Cat II/NTE/JTE Complete	7/72	92
Early Production		
Functional Config Audit	7/70	68
Physical Config Audit	7/70	68
First Lot Full Fund	1/69	55
First Lot Delivery	12/70	73
Second Lot Full Fund	8/70	69
Second Lot First Delivery	12/71	85
Third Lot Full Fund	1/72	86
Third Lot First Delivery	5/73	102
IOC	11/72	96

Table A-2. PATRIOT Data

Milestones	Dates	Months From EMD Start
Pre-EMD		
Milestone I	5/67	-58
Prototype Contract Award	5/67	-58
First Launch, Prototype CTV	11/70	-16
EMD		
Milestone II	2/72	-1
EMD Start/EMD Contract Award	3/72	0
EMD Article First Launch/CTV	11/73	20
First Guided Launch, DT&E Start	2/75	35
DT&E Complete	6/80	99
IOT&E Start	2/80	95
IOT&E Complete	7/72	96
Early Production		
Physical Config Audit	12/82	129
Production Readiness Review	8/80	101
Milestone IIA	9/80	102
First Lot Long Lead Release	11/79	92
First Lot Full Fund	10/80	103
First Lot Delivery	1/82	118
Milestone IIB	4/82	121
Second Lot Long Lead Release	2/81	107
Second Lot Full Fund	8/81	113
Second Lot First Delivery	7/83	136
Third Lot Long Lead Release	11/81	116
Third Lot Full Fund	5/82	122
Third Lot First Delivery	9/83	138
IOC	2/83	131

Table A-3. PATRIOT Mullti-Mode (MM) Data

Milestones	Dates	Months From Prototype Start
Pre-EMD		
Prototype Contract Award	7/89	0
First Guided Launch, Prototype	4/92	33
Last Guided Launch, Prototype	10/93	51

Table A-4. Stinger Data

Milestones	Dates	Months From EMD Start
Pre-EMD		
Milestone I	2/71	-16
Advanced Development Contract Award	9/71	-9
EMD		
Milestone II	5/72	-1
EMD Start/EMD Contract Award	6/72	0
Critical Design Rev	3/73	9
First Guided Launch/DT&E Start	11/73	17
DT&E Complete	10/76	52
IOT&E Start	10/76	52
IOT&E Complete	4/77	58
Early Production		
Production Readiness Review	4/76	46
Milestone IIA	12/77	66
First Lot Long Lead Release	12/77	66
First Lot Full Fund	4/78	70
First Lot Delivery	12/79	90
Milestone IIB	6/78	72
Second Lot Full Fund	4/79	82
Second Lot First Delivery	2/81	104
IOC	2/81	104

Table A-5. Standard Missile-2 Data

Milestones	Dates	Months From EMD Start
Pre-EMD		
Milestone I	7/70	-22
Prototype Contract Award	7/70	-22
EMD		
EMD Start/EMD Contract Award	5/72	0
Critical Design Rev	10/73	17
First Guided Launch, DT&E Start	12/74	31
DT&E Complete	5/77	60
IOT&E Start	9/76	52
IOT&E Complete	7/77	62
Early Production		
First Lot Full Fund	6/76	49
First Lot Delivery	4/78	71
Second Lot Full Fund	6/77	73
Second Lot First Delivery	2/79	81
Third Lot Full Fund	1/79	80
Third Lot First Delivery	3/80	94
IOC	9/77	64

Table A-6. Sprint Data

Milestones	Dates	Months From EMD Start
EMD		
EMD System Contract Award	5/63	0
First Guided Launch/DT&E Start	11/65	30
DT&E Complete	8/70	87
IOT/E Start	10/70	89
IOT&E Complete	12/73	127
IOC	6/74	133

Table A-7. Spartan Data

Milestones	Dates	Months From EMD Start
Pre-EMD		
Milestone I or Equivalent	3/65	-7
EMD		
EMD System Contract Award	10/65	0
First Guided Launch/DT&E Start	3/68	29
DT&E Complete	3/70	53
IOT&E Start	4/70	54
IOT&E Complete	6/73	92
First Lot Full Fund	10/70	60
First Lot Delivery	12/72	86
IOC	7/74	105

Table A-8. ERINT-1 Data

Milestones	Dates	Months From Prototype Start
Pre-EMD		
Prototype Contract Award	11/89	0
First CTV Launch, Prototype	6/92	31
First Guided Launch, Prototype	6/93	43
Last Guided Launch, Prototype	6/94	55

Table A-9. Sparrow F Data

Milestones	Dates	Months from EMD Start
Pre-EMD		
Requirements Issue Date	12/65	–7
EMD		
EMD Start/EMD Contract Award	7/66	0
Start Test Article Assembly	7/67	12
Deliver First EMD Article	11/67	16
First Guided Launch, CDT Start	3/68	20
CDT Complete	11/68	28
NTE Start	12/69	41
NTE Complete	2/72	67
OPEVAL Start	5/72	70
OPEVAL Complete	9/74	98
Early Production		
Milestone III	10/74	99
First Production Lot Full Funding	11/74	100
First Production Lot Delivery	1/76	114
Initial Operational Capability	4/76	117

Table A-10. Sparrow M Data

Milestones	Dates	Months From EMD Start
Pre-EMD		
Requirements Issue Date	12/74	–42
Milestone I or Equivalent	1/75	–39
Prototype Contract Award	8/76	–20
EMD		
EMD Start/EMD Contract Award	4/78	0
First Guided Launch, CTE Start	4/80	24
CTE Complete	8/80	28
JTE Start	8/80	28
JTE Complete	2/81	34
IOT&E Start	6/81	38
Early Production		
Milestone IIIA (FY81 Go-Ahead)	3/81	35
First Production Lot Delivery	1/83	57
Milestone IIIB (DNSARC III)	11/82	55
Initial Operational Capability	1/83	57

Table A-11. Sidewinder L Data

Milestones	Dates	Months From EMD Start
Pre-EMD		
Milestone I or Equivalent	10/70	–21
Prototype Contract Award	6/71	–13
First Guided Launch, Prototype	4/72	–3
EMD		
EMD Start/EMD Contract Award	7/72	0
Deliver First EMD Article	5/73	10
First Guided Launch, CTE Start	10/73	15
CTE Complete	5/74	22
JTE Start	8/74	25
JTE Complete	3/75	32
OPEVAL/IOT&E Start	1/75	30
OPEVAL/IOT&E Complete	12/75	41
Early Production		
Milestone IIIA	1/76	42
First Production Lot Long Lead Release	4/76	45
First Production Lot Delivery	3/78	68
Milestone IIIB	4/78	69
Initial Operational Capability	5/78	70

Table A-12. Sidewinder M Data

Milestones	Dates	Months From EMD Start
EMD		
Milestone II or Equivalent	2/76	0
EMD Start/EMD Contract Award	2/76	0
First Guided Launch, CTE Start	2/78	24
Early Production		
CTE Complete	5/79	39
Initial Operational Capability	9/82	79

Table A-13. Phoenix A Data

Milestones	Dates	Months From EMD Start
EMD		
Milestone II or Equivalent	12/62	0
EMD Start/EMD Contract Award	12/62	0
Deliver First EMD Article	8/64	20
First Captive Flight, EMD	1/65	25
First Guided Launch, CDT Start	5/66	41
CDT Complete	10/73	130
NTE Start	6/73	126
NTE Complete	6/74	138
OPEVAL Start	8/74	140
OPEVAL Complete	7/76	163
Early Production		
Milestone IIIA	11/70	95
First Production Lot Long Lead Release	12/70	96
First Production Lot Full Funding	12/71	108
First Production Lot Delivery	3/73	123
Second Production Lot Full Funding	12/72	120
Second Production Lot First Delivery	2/74	134
Third Production Lot Full Funding	12/73	132
Third Produciton Lot First Delivery	2/75	146
Initial Operational Capability	12/73	132

Table A-14. Phoenix C Data

Milestones	Dates	Months From EMD Start
EMD		
Milestone II or Equivalent	10/76	−11
EMD Start/EMD Contract Award	9/77	0
Deliver First EMD Article	2/79	17
First Captive Flight, EMD	7/79	22
First Guided Launch, CDT Start	4/80	31
CDT Complete	2/82	54
NTE Start	5/82	56
NTE Complete	11/82	62
OPEVAL Start	2/83	66
OPEVAL Complete	6/84	81
Early Production		
First Production Lot Long Lead Release	9/79	24
First Production Lot Full Funding	11/79	26
First Production Lot Delivery	8/82	59
Milestone IIIB	5/88	128
Second Production Lot Long Lead Release	6/81	45
Second Production Lot Full Funding	10/81	49
Second Production Lot First Delivery	7/83	70
Third Production Lot Long Lead Release	6/82	57
Third Production Lot Full Funding	10/82	61
Third Production Lot First Delivery	6/84	81
Initial Operational Capability	12/86	111

Table A-15. AMRAAM Data

Milestones	Dates	Months From EMD Start
Pre-EMD		
Milestone 0	10/75	–74
Justifications for Major System Start	11/76	–61
Program Decision Memorandum	3/78	–45
RFP, Concept Exploration Studies	3/76	–69
Concept Exploration Contract Award	7/76	–65
Concept Exploration Studies Complete	7/77	–53
Milestone I or Equivalent	11/78	–37
Prototype Contract Award	2/79	–34
First CTV Launch, Prototype	6/80	–18
First Guided Launch, Prototype	8/81	–4
EMD		
Milestone II or Equivalent	11/82	11
EMD Start/EMD Contract Award	12/81	0
Preliminary Design Review	9/82	9
Critical Design Review	3/85	39
95% Drawing Release	12/83	24
Start Test Article Fabrication	5/82	5
Start Test Article Assembly	8/82	8
Start Test Article Major Assembly	9/82	9
Complete First Guidance Section	11/82	11
Start Final Assembly	1/84	25
Deliver First EMD Article	3/84	27
First Captive Flight, EMD	2/84	26
First Guided Launch, DT&E/IOT&E	5/85	41
Functional Configuration Audit	12/87	72
Early Production		
Production Readiness Review (PRR)	8/82	8
PRR #2	4/85	40
PRR #3	4/86	52
Milestone IIIA	4/87	64
First Production Lot Long Lead Release	11/86	59
First Production Lot Full Funding	10/87	70
First Production Lot Delivery	9/88	81
Second Production Lot Long Lead Release	12/87	72
Second Production Lot Full Funding	7/88	79
Second Production Lot First Delivery	8/89	92
Third Production Lot Long Lead Release	10/88	82
Third Production Lot Full Fuinding	7/89	91
Third Production Lot First Delivery	8/90	104
Initial Operational Capability	9/91	117

Table A-16. Maverick EO Data

Milestones	Dates	Months From EMD Start
Pre-EMD		
Requirements Issue Date	7/64	–48
Milestone I or Equivalent	12/66	–19
EMD		
Milestone II or Equivalent	9/68	2
EMD Start/EMD Contract Award	7/68	0
Preliminary Design Review	3/69	8
Critical Design Review	5/70	22
95% Drawing Release	6/69	11
Start Test Article Fabrication	1/69	6
Start Final Assembly	6/69	11
First Guided Launch, Cat I Start	12/69	17
Cat I Complete	11/70	28
Cat II Start	2/71	31
Cat II Complete	9/71	38
Functional Configuration Audit	12/70	29
Physical Configuration Audit	7/73	60
Early Production		
Milestone IIIA	6/71	35
First Production Lot Full Funding	7/71	36
First Production Lot Delivery	8/72	49
Milestone IIIB	9/72	50
Second Production Lot Full Funding	11/72	52
Second Production Lot First Delivery	1/74	66
Third Production Lot Full Funding	10/73	63
Third Production Lot First Delivery	11/74	76
Initial Operational Capability	2/73	55

Table A-17. Maverick IIR Data

Milestones	Dates	Months From EMD Start
Pre-EMD		
Milestone I or Equivalent	11/73	–59
Prototype Contract Award	4/74	–54
First Launch, Prototype	10/75	–36
EMD		
Milestone II or Equivalent	9/76	–25
EMD Start/EMD Contract Award	10/78	0
Preliminary Design Review	5/79	7
Critical Design Review	5/80	19
95% Drawing Release	11/79	13
Complete First Guidance Section	5/80	19
First Captive Flight, EMD	6/80	20
Deliver First EMD Article	10/80	24
First Guided Launch, DT&E Start	12/80	26
DT&E Complete	4/82	42
IOT&E Start	3/81	29
IOT&E Complete	8/82	46
Functional Configuration Audit	11/82	44
Physical Configuration Audit	11/84	68
Production Readiness Review	2/83	52
Early Production		
Milestone IIIA	3/82	41
First Production Lot Long Lead Release	4/82	42
First Production Lot Full Funding	9/82	47
First Production Lot Delivery	10/83	60
Milestone IIIB	8/82	46
Second Production Lot Full Funding	4/83	54
Second Production Lot First Delivery	11/85	85
Third Production Lot Long Lead Release	4/-84	66
Third Production Lot Full Funding	4/85	78
Third Production Lot First Delivery	8/86	94
Initial Operational Capability	2/86	88

Table A-18. SRAM A Data

Milestones	Dates	Months From EMD Start
Pre-EMD		
Requirements Issue Date	3/64	–32
Milestone I or Equivalent	5/65	–18
RFP, Contract Definition	7/65	–16
Contract Definition, Contract Award	11/65	–12
EMD		
Milestone II or Equivalent	10/66	–1
EMD Start/EMD Contract Award	11/66	0
Preliminary Design Review	9/67	10
Critical Design Review	12/69	37
First Guided Launch, Cat I Start (B-52)	7/69	32
Cat I Start (FB-111)	4/70	46
Cat I Complete (B-52)	8/70	44
Cat I Complete (FB-111)	2/71	51
Cat II Start (B-52)	9/70	45
Cat II Start (FB-111)	4/71	53
Cat II Complete (B-52)	12/70	48
Cat II Complete (FB-111)	7/71	56
Early Production		
Milestone IIIA	1/70	38
First Production Lot Long Lead Release	6/70	43
First Production Lot Full Funding	1/71	50
First Production Lot Delivery	3/72	64
Milestone IIIB	12/70	49
Initial Operational Capability	8/72	69

Table A-19. Harpoon Data

Milestones	Dates	Months From EMD Start
Pre-EMD		
Milestone I or Equivalent	11/70	–22
Prototype Contract Award	6/71	–15
First Launch, Prototype	12/72	3
EMD		
Milestone II or Equivalent	4/73	7
EMD Start/EMD Contract Award	9/72	0
95% Drawing Release	7/74	22
Start Test Article Fabrication	3/73	6
Start Test Article Assembly	8/73	11
Deliver First EMD Article	2/74	17
First Guided Launch, CTE Start	3/74	18
CTE Complete	11/74	26
NTE Start	10/74	25
NTE Complete	6/75	33
OPEVAL Start	8/75	38
OPEVAL Complete	3/77	54
Early Production		
Milestone IIIA	11/75	33
First Production Lot Long Lead Release	6/75	33
First Production Lot Full Funding	2/76	41
First Production Lot Delivery	2/77	53
Milestone IIIB	9/77	60
Initial Operational Capability	7/77	58

Table A-20. ALCM Data

Milestones	Dates	Months From EMD Start
Pre-EMD		
Milestone I or Equivalent	2/74	–48
Prototype Contract Award	2/74	–48
Prototype Guidance Award	10/75	–28
First Launch, Prototype	9/76	–17
EMD		
Milestone II or Equivalent	1/77	–13
EMD Start/EMD Contract Award	2/78	0
Preliminary Design Review	6/77	–8
First Captive Flight, EMD	5/79	15
First Guided Launch, DT&E Start	8/79	18
DT&E Complete	5/81	39
Production Readiness Review	6/80	28
Early Production		
Milestone IIIA	4/80	26
First Production Lot Long Lead Release	10/79	20
First Production Lot Full Funding	3/80	25
First Production Lot Delivery	11/81	45
Second Production Lot Long Lead Release	10/80	32
Second Produciton Lot 1s Delivery	12/82	57
Third Production Lot Long Lead Release	10/81	44
Third Produciton Lot First Delivery	10/83	68
Initial Operational Capability	12/82	58

Table A-21. HARM Data

Milestones	Dates	Months From EMD Start
Pre-EMD		
Milestone I or Equivalent	6/72	–63
Prototype Contract Award	11/74	–34
First Delivery, Prototype	12/75	–21
First CTV Launch, Prototype	2/76	–20
First Guided Launch, Prototype	10/76	-11
EMD		
Milestone II or Equivalent	2/78	5
EMD Start/EMD Contract Award	9/77	0
First Captive Flight, EMD	11/78	14
First CTV Launch, EMD	2/79	17
First Guided Launch, CTE Start	4/79	19
CTE Complete	10/80	37
NTE/IOT&E/OPEVAL Start	8/81	47
NTE/IOT&E/OPEVAL Complete	10/82	61
Production Readiness Review	8/80	35
Early Production		
Milestone IIIA	3/82	54
First Production Lot Long Lead Release	1/81	40
First Production Lot Full Funding	12/81	51
First Production Lot Delivery	11/82	62
Second Production Lot Long Lead Release	11/81	50
Second Production Lot First Delivery	5/83	68
Initial Operational Capability	11/83	74

Table A-22. Hellfire Data

Milestones	Dates	Months From EMD Start
EMD		
Milestone II or Equivalent	2/76	–19
EMD Start/EMD Contract Award (guidance system)	9/77	0
First CTV Launch	6/78	9
First Guided Launch, DT&E Start	10/78	13
IOT&E Start	6/80	33
IOT&E Complete	7/80	34
Early Production		
Milestone IIIA	11/81	50
First Lot Long Lead Release	8/81	47
First Lot Full Fund	3/82	54
First Lot First Delivery	10/83	73
Second Lot Full Fund	1/83	64
Second Lot First Delivery	10/84	85
Third Lot Full Fund	6/84	81
Third Lot First Delivery	3/86	102
IOC	7/86	106

APPENDIX B

FLIGHT TEST DATA

Table B-1. PATRIOT A Test Launches

Program Phase	Test Environment	Test Phase	Fire Unit	Launch Date	Months From First Launch
I	Benign	POP	Demonstration	2/27/75	0
I	Benign	POP	Demonstration	3/31/75	1
I	Benign	POP	Demonstration	6/19/75	4
I	Benign	POP	Demonstration	7/18/75	5
I	Benign	POP	Demonstration	8/15/75	6
I	Benign	POP	Demonstration	9/16/75	7
I	Benign	EVAL	Demonstration	9/30/75	7
I	Benign	EVAL	Demonstration	11/5/75	8
I	Benign	EVAL	Demonstration	11/26/75	9
I	Benign	EVAL	Demonstration	1/22/76	11
I	Benign	EVAL	Demonstration	2/6/76	11
I	Benign	EVAL	Demonstration	2/19/76	12
II	ECM	EDT	Fire Unit 1	12/2/76	21
II	ECM	EDT	Fire Unit 1	1/28/77	23
II	ECM	EDT	Fire Unit 1	2/18/77	24
II	ECM	EDT	Fire Unit 1	3/30/77	25
II	ECM	EDT	Fire Unit 1	4/21/77	26
II	ECM	EDT	Fire Unit 1	5/21/77	27
II	ECM	EDT	Fire Unit 1	5/21/77	27
II	ECM	EDT	Fire Unit 1	6/2/77	27
III	ECM	EDT	Fire Unit 2	11/4/77	32
III	ECM	EDT	Fire Unit 2	2/8/78	35
III	ECM	EDT	Fire Unit 2	2/23/78	36
III	ECM	EDT	Fire Unit 2	2/27/78	36
III	ECM	EDT	Fire Unit 2	4/24/78	38
III	ECM	EDT	Fire Unit 2	5/17/78	39
III	ECM	EDT	Fire Unit 2	5/31/78	39
III	ECM	EDT	Fire Unit 2	5/31/78	39
III	ECM	EDT	Fire Unit 2	5/31/78	39
III	ECM	EDT	Fire Unit 2	6/22/78	40
III	ECM	EDT	Fire Unit 2	8/31/78	42
III	ECM	EDT	Fire Unit 2	9/28/78	43
III	ECM	EDT	Fire Unit 2	10/4/78	43
III	ECM	EDT	Fire Unit 2	10/4/78	43
III	ECM	EDT	Fire Unit 2	10/4/78	43
III	ECM	EDT	Fire Unit 2	10/12/78	44
III	ECM	EDT	Fire Unit 2	11/17/78	45
III	ECM	EDT	Fire Unit 2	1/19/79	47
III	ECM	EDT	Fire Unit 3	3/6/79	48
III	ECM	EDT	Fire Unit 3	4/6/79	49
III	ECM	EDT	Fire Unit 3	4/15/79	50
III	ECM	EDT	Fire Unit 3	5/1/79	50
III	ECM	EDT	Fire Unit 2	8/15/79	54
III	ECM	EDT	Fire Unit 3	9/1/79	54

Table B-1. PATRIOT A Test Launches (continued)

Program Phase	Test Environment	Test Phase	Fire Unit	Launch Date	Months From First Launch
III	ECM	EDT	Fire Unit 2	12/1/79	57
III	ECM	EDT	Fire Unit 3	12/10/79	57
III	ECM	OT	Fire Unit 5	2/5/80	59
III	ECM	OT	Fire Unit 5	2/5/80	59
III	ECM	OT	Fire Unit 5	2/5/80	59
III	ECM	OT	Fire Unit 5	2/25/80	60
III	ECM	OT	Fire Unit 5	2/25/80	60
III	ECM	OT	Fire Unit 5	3/7/80	60
III	ECM	OT	Fire Unit 5	3/7/80	60
III	ECM	OT	Fire Unit 4/5	3/26/80	61
III	ECM	OT	Fire Unit 4/5	3/26/80	61
III	ECM	DT	Fire Unit 5	5/5/80	62
III	ECM	DT	Fire Unit 5	5/19/80	63
III	ECM	DT	Fire Unit 5	6/11/80	64
III	ECM	DT	Fire Unit 5	6/25/80	64

Note: See the list of abbreviations at the end of this paper for meanings of abbreviations used here.

Table B-2. Standard Missile-2 Test Launches

Missile	Test Phase	Launch site	Launch Date	Months From EMD First Launch
FTR 3(ER)	Pre-EMD/DT	WSMR	11/72	-25
FTR 4(MR)	Pre-EMD/DT	WSMR	9/73	-15
FTR 5(A)	DT	WSMR	12/74	0
FTR 6(A)	DT	WSMR	4/75	4
FTR 7(A)	DT	WSMR	6/75	6
FTR 9(A)	DT	WSMR	9/75	9
FTR 10(A)	DT	WSMR	9/75	9
FTR 8(ER)	DT	WSMR	1/76	13
FTR 12(A)	DT	WSMR	3/76	15
FTR 11(A)	DT	WSMR	4/76	16
FTR 14(A)	DT	WSMR	5/76	17
FTR 17(ER)	DT	WSMR	6/76	18
FTR 15(ER)	DT	WSMR	8/76	20
FTR 16(ER)	DT	WSMR	8/76	20
FTR 23(ER)	DT	WSMR	9/76	21
FTR 24(ER)	DT	WSMR	9/76	21
FTR 25(ER)	OTE	USS Wainwright	9/76	21
FTR 19(A)	OTE	USS Wainwright	10/76	22
FTR 20(ER)	OTE	USS Wainwright	10/76	22
FTR 21(ER)	OTE	USS Wainwright	10/76	22
FTR 22(ER)	OTE	USS Wainwright	10/76	22
FTR 26(ER)	OTE	USS Wainwright	10/76	22
FTR 27(ER)	OTE	USS Wainwright	11/76	23
FTR 28(ER)	OTE	USS Wainwright	11/76	23
FTR 31(A)	OTE	USS Wainwright	11/76	23
FTR 32(A/ER)	OTE	USS Wainwright	11/76	23
FTR 18(ER)	DT-III	AEGIS EDM	12/76	24
FTR 29(ER)	DT-III	AEGIS EDM	2/77	26
FTR 30(A)	DT-III	AEGIS EDM	3/77	27
FTR 33(A/ER)	DT-III	AEGIS EDM	4/77	28
FTR 34(A)	DT-III	AEGIS EDM	4/77	28
FTR 36(A)	DT-III	AEGIS EDM	4/77	28
FTR 38(A)	DT-III	AEGIS EDM	4/77	28
FTR 40(A)	DT-III	AEGIS EDM	5/77	29
FTR 45(A)	DT-III	AEGIS EDM	5/77	29
FTR 35(A)	OT-III	AEGIS EDM	7/77	31
FTR 37(A)	OT-III	AEGIS EDM	7/77	31
FTR 39(A)	OT-III	AEGIS EDM	7/77	31
FTR 41(A)	OT-III	AEGIS EDM	7/77	31
FTR 42(A)	OT-III	AEGIS EDM	7/77	31
FTR 44(A)	OT-III	AEGIS EDM	7/77	31
FTR 46(A)	OT-III	AEGIS EDM	7/77	31
FTR 43(A)	DT-III	AEGIS EDM	3/78	39

Note: See the list of abbreviations at the end of this paper for meanings of abbreviations used here.

Table B-3. Sparrow F Test Launches: CDT and NTE

Missile Number	Phase	Test Site	Launch Date	Months FromTest Start	Months FromPhase Start	Cum. Launches	Cum. Launches by Phase
YR-403	CDT	PMTC	3/15/68	0.0	0.0	1	1
YR-415	CDT	PMTC	6/14/68	3.0	3.0	2	2
XR-406	CDT	PMTC	7/18/68	4.1	4.1	3	3
YR-417	CDT	PMTC	9/17/68	6.1	6.1	4	4
YR-414	CDT	PMTC	10/3/68	6.6	6.6	5	5
YR-416	CDT	PMTC	11/5/68	7.7	7.7	6	6
YR-418	CDT	PMTC	11/6/68	7.8	7.8	7	7
YR-421	NTE/CDT	PMTC	12/10/69	20.9	0.0	8	1
YR-425	NTE/CDT	PMTC	12/24/69	21.3	0.5	9	2
YR-422	NTE/CDT	PMTC	1/30/70	22.6	1.7	10	3
YR-426	NTE/CDT	PMTC	3/6/70	23.7	2.8	11	4
YR-424	NTE/CDT	PMTC	3/6/70	23.7	2.8	12	5
YR-427	NTE/CDT	PMTC	4/22/70	25.2	4.4	13	6
YR-423	NTE/CDT	PMTC	5/11/70	25.9	5.0	14	7
YR-431	NTE/CDT	PMTC	5/27/70	26.4	5.5	15	8
YR-430	NTE/CDT	PMTC	6/3/70	26.6	5.8	16	9
YR-428	NTE/CDT	PMTC	7/23/70	28.3	7.4	17	10
YR-429	NTE/CDT	PMTC	7/29/70	28.5	7.6	18	11
R-40008	NTE	PMTC	8/24/70	29.3	8.4	19	12
R-40006	NTE	PMTC	8/26/70	29.4	8.5	20	13
R-40012	NTE	PMTC	9/9/70	29.9	9.0	21	14
R-40011	NTE	PMTC	9/15/70	30.0	9.2	22	15
R-40007	NTE	PMTC	9/18/70	30.1	9.3	23	16
R-40004	NTE	PMTC	10/22/70	31.3	10.4	24	17
R-40013	NTE	PMTC	11/6/70	31.8	10.9	25	18
R-40026	NTE	PMTC	11/27/70	32.4	11.6	26	19
R-40035	NTE	PMTC	11/30/70	32.5	11.7	27	20
R-40003	NTE	PMTC	12/3/70	32.6	11.8	28	21
R-40021	NTE	PMTC	12/7/70	32.8	11.9	29	22
R-40032	NTE	PMTC	4/20/71	37.2	16.3	30	23

Note: See the list of abbreviations at the end of this paper for meanings of abbreviations used here.

Table B-3. Sparrow F Test Launches: CDT and NTE (continued)

Missile Number	Phase	TestSite	Launch Date	Months FromTest Start	Months FromPhase Start	Cum. Launches	Cum. Launches by Phase
R-40022	NTE	PMTC	4/24/71	37.3	16.4	31	24
R-40028	NTE	PMTC	5/4/71	37.6	16.8	32	25
R-40001	NTE	PMTC	5/13/71	37.9	17.1	33	26
R-40009	NTE	PMTC	8/4/71	40.7	19.8	34	27
R-40043	NTE	PMTC	9/16/71	42.1	21.2	35	28
R-40015	NTE	PMTC	9/23/71	42.3	21.4	36	29
R-40018	NTE	PMTC	10/8/71	42.8	21.9	37	30
R-40016	NTE	PMTC	10/19/71	43.2	22.3	38	31
R-40039	NTE	PMTC	10/27/71	43.4	22.6	39	32
R-40034	NTE	PMTC	11/22/71	44.3	23.4	40	33
R-40038	NTE	PMTC	12/11/71	44.9	24.0	41	34
R-40047	NTE	PMTC	12/11/71	44.9	24.0	42	35
R-40054	NTE	PMTC	1/5/72	45.7	24.9	43	36
R-40055	NTE	PMTC	1/5/72	45.7	24.9	44	37
R-40010	NTE	PMTC	1/14/72	46.0	25.2	45	38
R-40053	NTE	PMTC	1/19/72	46.2	25.3	46	39
R-40056	NTE	PMTC	1/24/72	46.4	25.5	47	40
R-40036	NTE	PMTC	1/28/72	46.5	25.6	48	41
R-40059	NTE	PMTC	2/2/72	46.7	25.8	49	42

Note: See the list of abbreviations at the end of this paper for meanings of abbreviations used here.

Table B-4. Phoenix A Test Launches: Initial CDT

Missile Number	Test Phase	Test Site	Launch Date	Months From Test Start	Cum. Launches
G4	R&D/CDT	PMTC	5/12/66	.0	1
G6	R&D/CDT	PMTC	9/8/66	3.9	2
G8	R&D/CDT	PMTC	2/28/67	9.6	3
G9	R&D/CDT	PMTC	3/17/67	10.2	4
G10	R&D/CDT	PMTC	11/3/67	17.8	5
G11	R&D/CDT	PMTC	11/22/67	18.4	6
G13	R&D/CDT	PMTC	1/18/68	20.3	7
G12	R&D/CDT	PMTC	3/18/68	22.2	8
G14	R&D/CDT	PMTC	4/16/68	23.2	9
G15	R&D/CDT	PMTC	5/16/68	24.2	10
G17	R&D/CDT	PMTC	7/30/68	26.6	11
G18	R&D/CDT	PMTC	8/27/68	27.6	12
G20	R&D/CDT	PMTC	11/27/68	30.6	13
G27	R&D/CDT	PMTC	3/8/69	33.9	14
G28	R&D/CDT	PMTC	3/8/69	33.9	15
G24	R&D/CDT	PMTC	3/10/69	34.0	16
G25	R&D/CDT	PMTC	3/10/69	34.0	17
G29	R&D/CDT	PMTC	4/2/69	34.7	18
G34	R&D/CDT	PMTC	7/8/69	37.9	19
G36	R&D/CDT	PMTC	7/16/69	38.2	20
G32	R&D/CDT	PMTC	8/1/69	38.7	21
G31	R&D/CDT	PMTC	9/11/69	40.0	22
G21	R&D/CDT	PMTC	10/9/69	41.0	23
G38	R&D/CDT	PMTC	11/3/69	41.8	24
G30	R&D/CDT	PMTC	12/15/69	43.2	25
G37	R&D/CDT	PMTC	12/24/69	43.5	26

Note: See the list of abbreviations at the end of this paper for meanings of abbreviations used here.

Table B-5. Phoenix C Test Launches: CDT

Missile Number	Test Phase	1st Captive Flight	Months From 1st. Captive to Launch	Launch Date	Months From Test Start	Cum. Launches
EDM1		7/23/79	9.0	-		
EDM3	CDT	2/8/80	2.3	4/17/80	0.0	1
EDM2	CDT	12/17/79	4.8	5/9/80	0.7	2
EDM4	CDT	5/21/80	1.9	7/17/80	3.0	3
EDM5	CDT	8/8/80	1.5	9/22/80	5.2	4
EDM6	CDT	9/15/80	1.2	10/21/80	6.1	5
EDM11	CDT	3/13/81	1.9	5/8/81	12.7	6
EDM9	CDT	2/3/81	6.8	8/26/81	16.3	7
EDM13	CDT	10/26/81	0.4	11/6/81	18.7	8
EDM15	CDT	6/12/81	6.2	12/15/81	20.0	9
EDM8	CDT	11/24/80	16.4	3/31/82	23.4	10

Note: See the list of abbreviations at the end of this paper for meanings of abbreviations used here.

Table B-6. AMRAAM Test Launches: DT&E/IOT&E

Missile Number	Test Site	Launch Date	Months From Test Start	Cum. Launches
AAVI-1	WSMR	5/14/85	0.0	1
AAVI-2	WSMR	8/7/85	2.8	2
AAVI-3	WSMR	9/17/85	4.1	3
AAVI-6	WSMR	3/25/86	10.4	4
AAVI-5	WSMR	4/18/86	11.1	5
AAVI-4	WSMR	5/8/86	11.8	6
AAVI-8	PMTC	6/2/86	12.6	7
AAVI-7	WSMR	6/4/86	12.7	8
AAVI-10	WSMR	7/3/86	13.6	9
AAVI-12	WSMR	7/15/86	14.0	10
AAVI-11	WSMR	7/29/86	14.5	11
AAVI-14	PMTC	8/9/86	14.9	12
AAVI-17	WSMR	8/20/86	15.2	13
AAVI-23	WSMR	9/12/86	16.0	14
AAVI-19	WSMR	9/30/86	16.6	15
AAVI-20	NWC	9/30/86	16.6	16
AAVI-25	NWC	10/15/86	17.1	17
AAVI-21	WSMR	10/24/86	17.4	18
AAVI-18	PMTC	11/6/86	17.8	19
AAVI-24	NWC	12/18/86	19.2	20
AAVI-26	EAFB	12/19/86	19.2	21
AAVI-15	WSMR	12/20/86	19.2	22
AAVI-16	WSMR	12/20/86	19.2	23
AAVI-30	EAFB	2/20/87	21.3	24
AAVI-32	EAFB	2/20/87	21.3	25
AAVI-31	WSMR	3/3/87	21.6	26
AAVI-33	PMTC	3/31/87	22.6	27
AAVI-44	WSMR	4/9/87	22.8	28
AAVI-45	EAFB	4/27/87	23.4	29
AAVI-40	WSMR	4/29/87	23.5	30
AAVI-42	WSMR	4/29/87	23.5	31
AAVI-37	PMTC	5/1/87	23.6	32
AAVI-35	PMTC	5/1/87	23.6	33
AAVI-52	WSMR	6/5/87	24.7	34
AAVI-36	WSMR	6/12/87	25.0	35
AAVI-49	WSMR	7/17/87	26.1	36
AAVI-58	EAFB	8/22/87	27.3	37
AAVI-51	PMTC	9/4/87	27.7	38
AAVI-46	EAFB	9/9/87	27.9	39
AAVI-47	EAFB	9/9/87	27.9	40
AAVI-55	PMTC	9/23/87	28.3	41
AAVI-61	EAFB	9/30/87	28.6	42
AAVI-43	PMTC	10/14/87	29.0	43

Note: See the list of abbreviations at the end of this paper for meanings of abbreviations used here.

Table B-6. AMRAAM Test Launches: DT&E/IOT&E (continued)

Missile Number	Test Site	Launch Date	Months From Test Start	Cum. Launches
AAVI-34	EAFB	10/15/87	29.1	44
AAVI-65	EAFB	10/22/87	29.3	45
AAVI-63	EAFB	11/18/87	30.2	46
AAVI-64	PMTC	11/22/87	30.3	47
AAVI-57	PMTC	12/8/87	30.8	48
AAVI-54	PMTC	12/8/87	30.8	49
AAVI-38	PMTC	12/10/87	30.9	50
AAVI-59	WSMR	12/17/87	31.1	51
AAVI-68	PMTC	2/9/88	32.9	52
AAVI-50	WSMR	2/22/88	33.3	53
AAVI-53	WSMR	2/22/88	33.3	54
AAV-2	EAFB	3/25/88	34.4	55
AAVI-41	WSMR	4/7/88	34.8	56
AAVI-67	WSMR	4/7/88	34.8	57
AAVI-75	EAFB	4/8/88	34.8	58
AAV-4	PMTC	4/22/88	35.3	59
AAVI-66	EAFB	5/27/88	36.5	60
AAVI-39	PMTC	6/3/88	36.7	61
AAVI-72	PMTC	6/24/88	37.4	62
AAV-3	EAFB	7/21/88	38.3	63
AAVI-80	PMTC	7/22/88	38.3	64
AAVI-70	NWC	7/29/88	38.5	65
_	EAFB	8/3/88	38.7	66
_	EAFB	8/3/88	38.7	67
_	EAFB	8/10/88	38.9	68
_	EAFB	8/10/88	38.9	69
_	WSMR	8/23/88	39.4	70
_	EAFB	9/7/88	39.8	71
_	EAFB	9/12/88	40.0	72
_	EAFB	9/26/88	40.5	73
_	EAFB	11/16/88	42.1	74
_	EAFB	12/7/88	42.8	75
_	EAFB	12/7/88	42.8	76
_	EAFB	12/9/88	42.9	77
_	EAFB	12/13/88	43.0	78
_	EAFB	12/16/88	43.1	79
_	EAFB	12/21/88	43.3	80
_	PMTC	1/19/89	44.3	81
_	NWC	1/24/89	44.4	82
_	EAFB	1/25/89	44.4	83
_	PMTC	1/26/89	44.5	84
_	WSMR	1/30/89	44.6	85
_	WSMR	5/13/89	48.0	86
_	_	5/19/89	48.2	87

Note: See the list of abbreviations at the end of this paper for meanings of abbreviations used here.

Table B-6. AMRAAM Test Launches: DT&E/IOT&E (continued)

Missile Number	Test Site	Launch Date	Months From Test Start	Cum. Launches
–	–	5/2/89	47.6	88
–	–	6/7/89	48.8	89
–	–	6/10/89	48.9	90
–	–	6/14/89	49.1	91

Note: See the list of abbreviations at the end of this paper for meanings of abbreviations used here.

Table B-7. Maverick EO Test Launches: Categories I and II and R&D Follow-On

Missile Number	Phase	Test Site	Launch Date	Months From Test Start	Months From Phase Start	Cum. Launches	Cum. Launches by Phase
3	Cat I	HAFB	12/18/69	0.0	0.0	1	1
4	Cat I	HAFB	2/25/70	2.3	2.3	2	2
8	Cat I	HAFB	3/9/70	2.7	2.7	3	3
12	Cat I	HAFB	4/29/70	4.3	4.3	4	4
13	Cat I	HAFB	5/28/70	5.3	5.3	5	5
11	Cat I	HAFB	6/1/70	5.4	5.4	6	6
14	Cat I	HAFB	6/18/70	6.0	6.0	7	7
15	Cat I	HAFB	6/18/70	6.0	6.0	8	8
17	Cat I	HAFB	8/27/70	8.3	8.3	9	9
19	Cat I	HAFB	10/2/70	9.5	9.5	10	10
24	Cat I	HAFB	10/20/70	10.1	10.1	11	11
18	Cat I	HAFB	11/9/70	10.7	10.7	12	12
20	Cat I	HAFB	11/24/70	11.2	11.2	13	13
26	Cat I	HAFB	11/30/70	11.4	11.4	14	14
27	Cat I	HAFB	12/11/70	11.8	11.8	15	15
54	Cat II	HAFB	2/10/71	13.8	0.0	16	1
51	Cat II	HAFB	2/17/71	14.0	0.2	17	2
52	Cat II	HAFB	2/22/71	14.2	0.4	18	3
50	Cat II	HAFB	2/24/71	14.2	0.5	19	4
53	Cat II	HAFB	3/8/71	14.6	0.9	20	5
55	Cat II	HAFB	3/16/71	14.9	1.1	21	6
59	Cat II	HAFB	3/22/71	15.1	1.3	22	7
61	Cat II	HAFB	3/24/71	15.2	1.4	23	8
60	Cat II	HAFB	3/29/71	15.3	1.5	24	9
58	Cat II	HAFB	4/5/71	15.6	1.8	25	10
65	Cat II	HAFB	4/20/71	16.0	2.3	26	11
75	Cat II	HAFB	5/5/71	16.5	2.8	27	12
71	Cat II	HAFB	5/10/71	16.7	2.9	28	13
79	Cat II	HAFB	5/13/71	16.8	3.0	29	14
70	Cat II	HAFB	5/17/71	16.9	3.2	30	15
82	Cat II	HAFB	5/20/71	17.0	3.3	31	16
68	Cat II	HAFB	6/2/71	17.5	3.7	32	17
73	Cat II	HAFB	6/7/71	17.6	3.8	33	18
81	Cat II	HAFB	6/9/71	17.7	3.9	34	19
74	Cat II	HAFB	6/14/71	17.9	4.1	35	20
84	Cat II	HAFB	6/17/71	18.0	4.2	36	21
80	Cat II	HAFB	6/23/71	18.1	4.4	37	22
69	Cat II	HAFB	6/25/71	18.2	4.4	38	23
77	Cat II	HAFB	6/28/71	18.3	4.5	39	24
67	Cat II	HAFB	6/30/71	18.4	4.6	40	25
72	Cat II	HAFB	7/6/71	18.6	4.8	41	26
76	Cat II	HAFB	7/8/71	18.6	4.9	42	27

Note: See the list of abbreviations at the end of this paper for meanings of abbreviations used here.

Table B-7. Maverick EO Test Launches: Categories I and II and R&D Follow-On (continued)

Missile Number	Phase	Test Site	Launch Date	Months From Test Start	Months From Phase Start	Cum. Launches	Cum. Launches by Phase
86	Cat II	HAFB	7/12/71	18.8	5.0	43	28
83	Cat II	HAFB	7/22/71	19.1	5.3	44	29
89	Cat II	HAFB	7/26/71	19.2	5.5	45	30
90	Cat II	HAFB	7/28/71	19.3	5.5	46	31
96	Cat II	HAFB	7/30/71	19.4	5.6	47	32
91	Cat II	HAFB	8/17/71	20.0	6.2	48	33
88	Cat I	HAFB	8/26/71	20.3	6.5	49	34
97	Cat II	HAFB	9/2/71	20.5	6.7	50	35
66	Cat II	HAFB	9/2/71	20.5	6.7	51	36
87	Cat II	HAFB	9/8/71	20.7	6.9	52	37
93	R&DF.O.	HAFB	10/7/71	21.6	0.0	53	1
94	R&DF.O.	HAFB	10/12/71	21.8	0.2	54	2
21	R&DF.O.	HAFB	1/19/72	25.1	3.4	55	3
85	R&DF.O.	HAFB	1/21/72	25.1	3.5	56	4
95	R&DF.O.	HAFB	2/4/72	25.6	3.9	57	5
104	R&DF.O.	HAFB	4/10/72	27.7	6.1	58	6
106	R&DF.O.	HAFB	4/10/72	27.7	6.1	59	7
25	R&DF.O.	HAFB	4/24/72	28.2	6.6	60	8
112	R&DF.O.	EAFB	7/28/72	31.3	9.7	61	9
115	R&DF.O.	EAFB	8/4/72	31.6	9.9	62	10
92	R&DF.O.	EAFB	8/5/72	31.6	10.0	63	11
A1	DSARC	EAFB	9/15/72	32.9	11.3	64	12
A2	DSARC	EAFB	9/20/72	33.1	11.5	65	13
114	R&DF.O.	EAFB	10/4/72	33.6	11.9	66	14

Note: See the list of abbreviations at the end of this paper for meanings of abbreviations used here.

Table B-8. Maverick IIR Test Launches: DT&E/IOT&E

Missile Number	Phase	Test Site	Launch Date	Months From Test Start	Cum. Launches
3	DT&E	EAFB	12/4/80	0.0	1
1	DT&E	EAFB	12/12/80	0.3	2
4	DT&E	EAFB	1/23/81	1.6	3
2	DT&E	EAFB	2/4/81	2.0	4
6	DT&E	MAFB	2/22/81	2.6	5
7	IOT&E	MAFB	3/2/81	2.9	6
9	DT&E	DPG	3/23/81	3.6	7
11	DT&E	DPG	4/7/81	4.1	8
13	DT&E	EAFB	6/19/81	6.5	9
14	DT&E	EAFB	8/25/81	8.7	10
10	DT&E	EAFB	9/2/81	8.9	1
17	IOT&E	EAFB	10/8/81	10.1	12
23	DT&E	EAFB	11/23/81	11.6	13
21	DT&E	EAFB	12/3/81	12.0	14
19	IOT&E	DPG	12/12/81	12.3	15
28	IOT&E	DPG	4/2/82	15.9	16
22	DT&E	EAFB	4/9/82	16.1	17
26	DT&E	EAFB	4/13/82	16.3	18
18	IOT&E	DPG	5/7/82	17.1	19
20	IOT&E	DPG	5/15/82	17.3	20
20003	IOT&E	DPG	5/15/82	17.3	2
24	IOT&E	DPG	6/18/82	18.4	22
8	IOT&E	DPG	7/13/82	19.3	23
20004	IOT&E	DPG	7/13/82	19.3	24
12	IOT&E	DPG	8/7/82	20.1	25
20002	IOT&E	DPG	8/17/82	20.4	26

Note: See the list of abbreviations at the end of this paper for meanings of abbreviations used here.

Table B-9. SRAM Test Launches: Categories I and II

Missile Number	Aircraft	Phase	Test Site	Launch Date	Months From Test Start	Cum. Launches
101	B-52	Cat I	WSMR	7/29/69	0.0	1
102	B-52	Cat I	WSMR	10/16/69	2.6	2
104	B-52	Cat I	WSMR	2/11/70	6.5	3
201	B-52	Cat I	WSMR	2/18/70	6.7	4
103	B-52	Cat I	WSMR	2/25/70	6.9	5
107	B-52	Cat I	WSMR	3/30/70	8.0	6
202	F-111	Cat I	WSMR	4/8/70	8.3	7
113	F-111	Cat I	WSMR	5/20/70	9.7	8
110	B-52	Cat I	WSMR	5/22/70	9.8	9
109	F-111	Cat I	WSMR	6/10/70	10.4	10
106	B-52	Cat I	WSMR	6/18/70	10.7	11
117	F-111	Cat I	WSMR	7/1/70	11.1	12
114	B-52	Cat I	WSMR	7/17/70	11.6	13
310	B-52	Cat I	WSMR	8/7/70	12.3	14
301	B-52	Cat I	WSMR	8/11/70	12.4	15
203	B-52	Cat II	WSMR	9/3/70	13.2	16
112	F-111	Cat I	WSMR	9/16/70	13.6	17
205	F-111	Cat I	WSMR	9/22/70	13.8	18
303	B-52	Cat II	WSMR	9/24/70	13.9	19
304	B-52	Cat II	WSMR	9/28/70	14.0	20
302	F-111	Cat I	WSMR	9/30/70	14.1	21
207	B-52	Cat II	WSMR	10/7/70	14.3	22
401	B-52	Cat II	WSMR	11/2/70	15.2	23
206	B-52	Cat II	WSMR	11/17/70	15.6	24
307	B-52	Cat II	WSMR	11/25/70	15.9	25
105	B-52	Cat II	WSMR	11/25/70	15.9	26
306	B-52	Cat II	WSMR	12/16/70	16.6	27
204	F-111	Cat I	WSMR	12/18/70	16.7	28
111	F-111	Cat I	WSMR	1/19/71	17.7	29
208	F-111	Cat I	WSMR	1/29/71	18.0	30
309	F-111	Cat I	WSMR	2/25/71	18.9	31
315	F-111	Cat II	WSMR	4/13/71	20.5	32
108	F-111	Cat II	WSMR	4/28/71	21.0	33
209	F-111	Cat II	WSMR	5/18/71	21.6	34
314	F-111	Cat II	WSMR	5/25/71	21.9	35
316	F-111	Cat II	WSMR	6/15/71	22.6	36
313	F-111	Cat II	WSMR	6/22/71	22.8	37
403	F-111	Cat II	WSMR	7/7/71	23.3	38

Note: See the list of abbreviations at the end of this paper for meanings of abbreviations used here.

Table B-10. Harpoon Test Launches: Pre-EMD, CTE/NTE

Missile Number	Phase	Test Site	Launch Platform	Launch Date	Months From Test Start	Months From Phase Start	Cum. Launches By Phase
GTV1	Pre-EMD	PMTC	Aircraft	12/20/72	0.0	.0	1
GTV2	Pre-EMD	PMTC	Aircraft	1/24/73	1.2	1.2	2
GTV3	Pre-EMD	PMTC	Aircraft	3/9/73	2.6	2.6	3
GTV5	Pre-EMD	PMTC	Aircraft	3/14/73	2.8	2.8	4
GTV7	Pre-EMD	PMTC	Aircraft	3/23/73	3.1	3.1	5
GTV4	Pre-EMD	PMTC	Ship	5/3/73	4.4	4.4	6
GTV6	Pre-EMD	PMTC	Ship	5/23/73	5.1	5.1	7
GTV9	Pre-EMD	PMTC	Ship	6/1/73	5.4	5.4	8
GTV10	Pre-EMD	PMTC	Aircraft	6/11/73	5.7	5.7	9
GTV8	Pre-EMD/WSD	PMTC	Aircraft	11/6/73	10.6	10.6	10
GTV11	Pre-EMD/WSD	PMTC	Aircraft	11/29/73	11.3	11.3	11
GTV12	Pre-EMD/WSD	PMTC	Aircraft	12/10/73	11.7	11.7	12
PM1	CTE	PMTC	Aircraft	3/31/74	15.3	.0	1
PM2	CTE	PMTC	Aircraft	4/11/74	15.7	.4	2
PM5	CTE	PMTC	Ship	5/11/74	16.7	1.3	3
PM7	CTE	PMTC	Ship	5/16/74	16.8	1.5	4
PM11	CTE	PMTC	Ship	5/31/74	17.3	2.0	5
PM12	CTE	PMTC	Ship	6/5/74	17.5	2.2	6
PM4	CTE	PMTC	Aircraft	6/8/74	17.6	2.3	7
PM6	CTE	PMTC	Aircraft	6/18/74	17.9	2.6	8
PM8	CTE	PMTC	Aircraft	7/22/74	19.0	3.7	9
PM9	CTE	PMTC	Aircraft	7/25/74	19.1	3.8	10
PM14	CTE	PMTC	Ship	8/15/74	19.8	4.5	11
PM19	CTE	PMTC	Ship	9/26/74	21.2	5.9	12
PM10	CTE	PMTC	Aircraft	10/2/74	21.4	6.1	13
PM24	NTE	PMTC	Ship	10/24/74	22.1	.0	14
PM25	NTE	PMTC	Ship	11/1/74	22.4	.3	15
PM13	CTE	PMTC	Aircraft	11/11/74	22.7	.6	16
PM16	NTE	PMTC	Aircraft	11/22/74	23.1	1.0	17
PM31	NTE	PMTC	Aircraft	12/7/74	23.6	1.4	18
PM21	NTE	PMTC	Aircraft	12/15/74	23.8	1.7	19
PM27	NTE	PMTC	Aircraft	1/14/75	24.8	2.7	20
PM17	NTE	PMTC	Ship	1/23/75	25.1	3.0	21
PM26	NTE	PMTC	Ship	1/25/75	25.2	3.1	22
PM36	NTE	PMTC	Aircraft	2/24/75	26.2	4.0	23
PM30	NTE/CTE	PMTC	Ship	3/1/75	26.3	4.2	24
PM22	NTE	PMTC	Aircraft	4/10/75	27.6	5.5	25
PM33	NTE/CTE	PMTC	Ship	5/13/75	28.7	6.6	26
PM29	NTE/CTE	PMTC	Ship	5/28/75	29.2	7.1	27
PM32	NTE/CTE	PMTC	Ship	5/29/75	29.3	7.1	28
PM23	NTE	PMTC	Ship	6/12/75	29.7	7.6	29
PM34	NTE/CTE	PMTC	Ship	6/12/75	29.7	7.6	30
PM28	NTE	PMTC	Aircraft	6/14/75	29.8	7.7	31
PM35	NTE	PMTC	Ship	6/26/75	30.2	8.1	32
PM37	NTE	PMTC	Ship	6/27/75	30.2	8.1	33

Note: See the list of abbreviations at the end of this paper for meanings of abbreviations used here.

Table B-11. ALCM Test Launches: DT&E and DT&E Follow-On

Missile Number	Phase	Test Site	Launch Date	Months From Test Start	Months From Phase Start	Cum. Launches	Launches By Phase
F1	DT&E	UTTR	8/3/79	.0	.0	1	1
F2	DT&E	UTTR	9/6/79	1.1	1.1	2	2
F3	DT&E	UTTR	9/25/79	1.7	1.7	3	3
F6	DT&E	UTTR	10/9/79	2.2	2.2	4	4
F7	DT&E	UTTR	11/21/79	3.6	3.6	5	5
F10	DT&E	UTTR	11/29/79	3.9	3.9	6	6
F9	DT&E	UTTR	12/4/79	4.0	4.0	7	7
F4	DT&E	UTTR	12/18/79	4.5	4.5	8	8
F12	DT&E	UTTR	1/5/80	5.1	5.1	9	9
F5	DT&E	UTTR	1/22/80	5.7	5.7	10	10
F15	DT&E(F.O.)	UTTR	6/12/80	10.3	.0	11	1
F13	DT&E(F.O.)	UTTR	7/22/80	11.6	1.3	12	2
F8	DT&E(F.O.)	UTTR	8/21/80	12.6	2.3	13	3
78-0830	DT&E(F.O.)	UTTR	10/23/80	14.7	4.4	14	4
F14	DT&E(F.O.)	UTTR	11/12/80	15.4	5.0	15	5
F9R1	DT&E(F.O.)	UTTR	11/20/80	15.6	5.3	16	6
78-0831	DT&E(F.O.)	UTTR	2/19/81	18.6	8.3	17	7
F14R1	DT&E(F.O.)	UTTR	3/25/81	19.7	9.4	18	8
78-0834	DT&E(F.O.)	UTTR	4/16/81	20.4	10.1	19	9
F10R1	DT&E(F.O.)	UTTR	4/24/81	20.7	10.4	20	10
F12R1	DT&E(F.O.)	UTTR	4/30/81	20.9	10.6	21	11

Note: See the list of abbreviations at the end of this paper for meanings of abbreviations used here.

APPENDIX C

PROGRAM DESCRIPTIONS

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PROGRAM DESCRIPTIONS

IMPROVED HAWK (MIM-23B)

The Improved HAWK (IHAWK) system is intended to intercept enemy aircraft at low to medium altitudes. The Improved HAWK system is an evolution of the Basic HAWK, which was developed in the mid-1950s and deployed in the late 1950s and early 1960s. The IHAWK missile represents a total redesign from the Basic HAWK. Several of the system's ground elements were also upgraded. The complete system includes the MIM-23B missiles and launchers, the improved continuous wave acquisition radar (ICWAR) and pulse acquisition (PAR) detection radar, a range only radar (ROR), improved high power illuminator (IHPI) and information control center (ICC). The MIM-23B's guidance method is semi-active continuous wave radar with target illumination and command updates provided from ground-based radar. Raytheon is the prime contractor for both the Basic and Improved HAWK systems [21 and 22].

Advanced development for the IHAWK missile began in June 1962 with the award of an research, development, test and evaluation (RDT&E) contract to Raytheon (DA-19-020-AMC-0215Z). Engineering development for the missile began in November 1964; this marks the beginning of engineering and manufacturing development (EMD) in our database. A total of 55 RDT&E missiles were procured under the development contract. The engineering development effort was subsumed under the original contract. Engineering development of the ICWAR began in January 1966. Three rocket motor demonstration flights occurred between January and May 1966. The first R&D design model, less the ICWAR, was completed in July 1966. A guidance flight test occurred in September 1966. An additional engineering development contract was awarded Raytheon in April 1967. This contract is described as advanced production development. The first all-up R&D design model was completed in July 1967. The first flight of a wooden round missile was accomplished in August 1967; this initiated the R&D flight test program and marks first guided launch in our database [22 and 23].

The IHAWK missile's flight test program did not reflect contemporary classifications of test phases (i.e., DT&E and IOT&E). Instead, the flight test program was composed of smaller, more numerous, test segments. It appears that the equivalent of DT&E was composed of the R&D, Engineering Test, and CORE Test program phases. The R&D test phase consisted of launches of 25 RDT&E missiles occurring between August 1967 and October 1968. The Engineering Test phase included launches of seven RDT&E and nine industrial prototype (IP) missiles. Forty-one IP missiles were procured under an April 1968 contract (DAAH01-68-C-0703). The Engineering Test phase was accomplished between February and December 1969. The CORE Test Program consisted of launches of ten IP missiles between March and July 1970 [21].

The IHAWK's Performance Demonstration Test (PDT), Initial Production Test (IPT) and Initial Operational Test and Evaluation (IOTE), can be thought of as encompassing what is now categorized as IOT&E. All three test programs were performed with low rate initial production missiles, primarily from the FY69 lot. PDT (17 launches) occurred between January and April 1971. IPT (23 launches) occurred between May 1971 and July 1972. All eight IOTE launches were performed in July 1972. Figure C-1 presents IHAWK test phases over time and their associated launch rates.

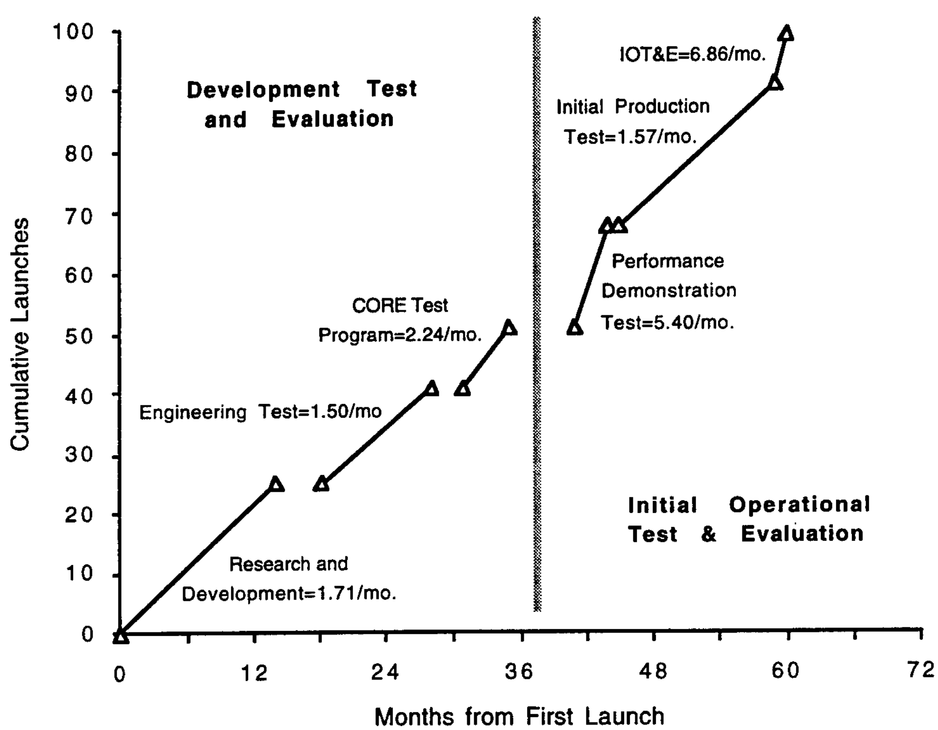

Figure C-1. IHAWK Flight Test Launches

The first production contract was awarded in January 1969. The contract covered 100 FY69 missiles and can be thought of as the equivalent to a low rate initial production contact. The first production delivery was accomplished in December 1970 with the last delivery in October 1971. Most of the FY69 missiles were used in initial operational flight testing. The second production contract was for 330 FY70 missiles; the contract was awarded in August 1970 and deliveries were made between December 1971 and April 1973. The FY70 missiles were the first production missiles in the operational inventory. IOC was accomplished in November 1972 [23].

PATRIOT (MIM-104A)

PATRIOT is a surface-to-air defense guided missile system with three unique key features: a multi-function, phased-array radar, track-via-missile (TVM) guidance, and automated operations with capability for human override. The single multi-function, phased-array radar performs the function that requires nine separate radars within currently operational systems [24]. Designed to operate under all weather conditions and to be capable of destroying maneuvering aircraft at all altitudes, the PATRIOT system is capable of guiding several missiles to attack multiple aircraft/targets simultaneously in a severe electronic jamming environment. Breakthrough in microelectronics technology and component standardization have given the PATRIOT system a high degree of reliability and permitted a greatly improved system readiness [25]. Raytheon was awarded the advance development contract in 1965 has remained the sole-source, prime contractor.

The PATRIOT guided missile (GM) consists of a missile mounted within a canister that functions as both a shipping and storage container and a launch tube. GMs are stacked in groups of four per launcher. The fire unit is centered on a mobile battle-management unit known as the MSQ-104 Engagement Control Station (ECS). Each fire unit includes one MPQ-53 radar, incorporating several phased-array antennas, which perform all search, track, command, and electronic counter-countermeasures (ECCM) functions. Each fire unit and its radar can track and prioritize more than 100 targets. The ECS controls up to eight launchers with 32 ready-to-fire missiles, which are stored and transported as ready rounds in their launch tubes. The missile weighs 1.7 tons and has a maximum speed of Mach 5. The system's maximum range is more than 80 km [25].

The PATRIOT program, which evolved from SAM-D concept formulation, began in 1965 when the Secretary of Defense (SECDEF) authorized Concept Definition (CD). The SAM-D concept resulted from the U.S. Army Missile Command (MICOM) studies of the Army Air Defense System for the 1970s (ADDS-70). In May 1967, a formal Advanced

Development (AD) contract (DAAH01-67-C-1995) was awarded to Raytheon Company as the prime contractor. AD included launches of unguided test missiles as well as the design, fabrication, and testing of a demonstration radar. The first fight test occurred in November 1980. We classify this as a CTV flight.

Milestone II occurred in February 1972 and the full-scale engineering development contract (DAAH01-72-C-0106) was awarded in March 1972 [10]. In February 1974, the SAM-D development program was restructured to permit early flight verification of the TVM guidance system. ASARC/DSARC decisions in January 1976 approved the program to resume the full-scale engineering development, and the program was finally renamed PATRIOT in May 1976. The Engineering Development contract is divided into three phases; Phase I, demonstrate proof of principle (POP) of TVM guidance; Phase II, demonstrate operation of TVM guidance and Fire Section performance in an ECM environment; and Phase III, complete PATRIOT system design and fabrication. Initial operational testing was completed as a part of Phase III [24, 26].

The first flight testing of the PATRIOT missile was performed with a demonstration model fire unit incorporating a modified HAWK launcher. The first non-guided (CTV) launch of a PATRIOT occurred in November 1973. The first guided launch occurred in February 1975, initiating the POP flight test program. The POP program consisted of six launches, followed immediately by five (eight if CTV launches are counted) additional evaluation launches; the 11 guided launches constituted the Phase I flight test program. The last launch in Phase I occurred in February 1976. All Phase I launches were performed using the demonstration model fire unit in a benign ECM environment [24].

There was a delay of ten months between the Phase I and Phase II testing. Phase II Engineering Development Testing (EDT) used the first PATRIOT fire unit (Fire Unit 1). Because the capability to perform in an ECM environment is embedded in the PATRIOT fire unit, testing in this environment required the fire unit's availability. Phase II also featured the first multiple shot engagement (MSE) test. Phase II testing included eight launches achieved between December 1976 and June 1977 [24].

Phase III testing included EDT, development testing (DT) and initial operational testing (OT). Phase III EDT was performed with fire units two and three. The first Phase III EDT launch occurred in November 1977. It is unclear from the information available where EDT ended and DT began. We make the assumption that all launches from fire units two and three were EDT launches. Phase III testing was performed with two different missile hardware configurations. The first EDT launches were with the Regular Airborne Guidance (RAG) configuration while later launches included the Modular Digital Airborne

Guidance (MDAG) configuration, which became the production standard. In all, 14 RAG and 13 MDAG missiles were launched using fire units two and three. The last launch of these missiles was in December 1979.

Because of problems during EDT, DT and OT schedules were revised [27]:

> Following the decision in 1977 to accelerate the development of the PATRIOT missile system, the operational test was planned as a part of a OT/DT program with DT both preceding and following OT. The plan in the spring of 1979 called for a full system demonstration by the contractor in May-June 1979; the first part of DT during July-August; Phase I of OT (Individual/Collective training) was to be conducted from 19 March-30 August 1979 concurrently with other contractor and DT tests; an OT pretest exercise was scheduled from 31 August to 13 September 1979. OT Phase II (testing) was planned for 14 September to 13 November. Because of system difficulties encountered primarily with the operational software, the integrated battalion demonstration and system training were not accomplished as planned. DT was deferred until after OT. The start of OT phase II was delayed until 3 December and several OT objectives/ subobjectives were deferred until post OT developmental testing. Again, due to system problems, OT was temporarily suspended from 8 December 1979 through 8 January 1980. OT resumed on 9 January and was officially concluded on 26 March 1980.

Fire units four and five were used for OT testing. OT II contained four subsets of tests with missile test launches encompassing the last subset. Nine missile launches were accomplished during four MSE tests. The tests occurred during February and March 1980. OT testing reveled some shortfalls in the areas of reliability, maintainability, target identification, and electronic counter-countermeasures (ECCM) performance. Due to these shortfalls, only limited production was approved with a prescription of a series of four test units to demonstrate system performance, reliability, and maintainability prior to a full production decision. These four test units were launched in May and June 1980 during follow-on DT.

Figure C-2 presents cumulative test launches over time for the PATRIOT EMD program. Launch rates are not averages but represent slope coefficients of the regression lines.

The long lead release for the first limited production lot (FY80) occurred in November 1979. This first lot was for 155 missiles. Full funding for the FY80 lot occurred one month after the August 1980 DSARC IIIA limited production decision. The first delivery of an FY80 missile was in January 1982. This marks the first production delivery in our database. Long-lead and full-funding release for the 92-missile FY81 lot occurred in February and August 1981; first delivery occurred in July 1983. Long lead release for the FY82 lot occurred in November 1981. The FY82 lot of 176 missiles was considered the first full production lot. The DSARC IIIB full-production decision occurred in April 1982 and the full-funding release for the FY82 lot was in May 1982. The physical configuration audit was held in December 1982, and IOC was achieved in February 1983 [28].

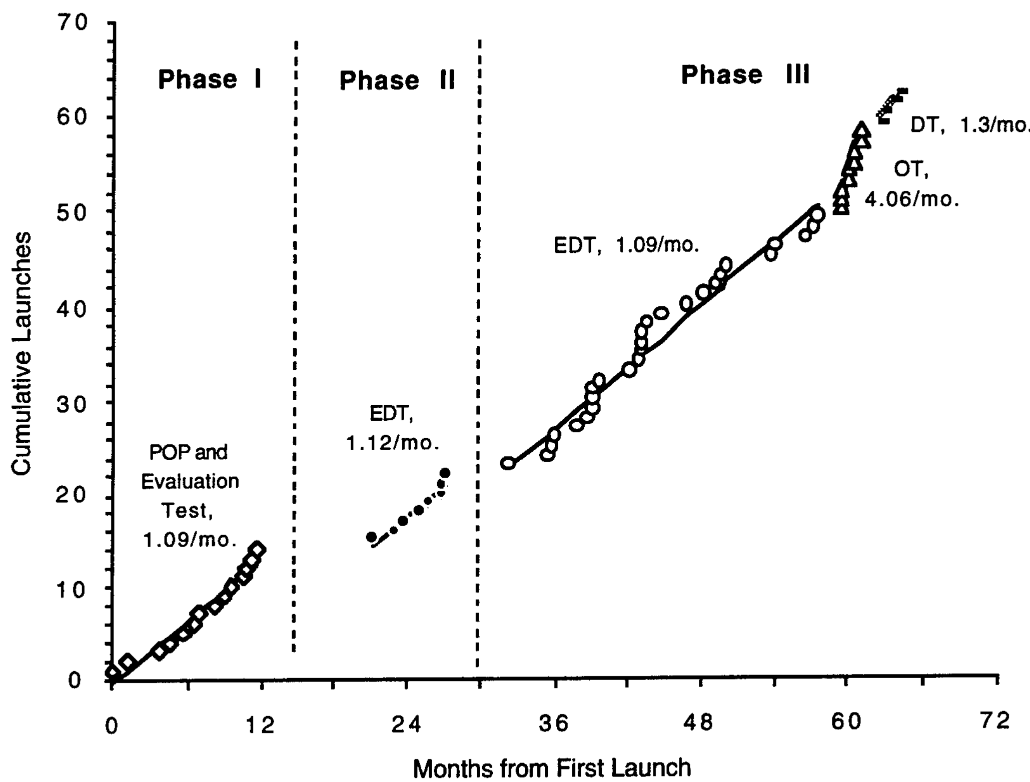

Figure C-2. PATRIOT Flight Test Launches

PATRIOT MULTI-MODE (MM)

The PATRIOT MM was one of the two candidates, along with the ERINT-1, for the PAC-3 (PATRIOT Advance Capability 3) missile system. The PAC-3 is an upgrade version of the PATRIOT Air Defense System PAC-2. While the PAC-1 and PAC-2 missiles are optimized for use against the relatively short-range missiles, the PAC-3 is designed for use against longer range missiles. The PAC-3 improvements are expected to provide an entire system upgrade, both missile and ground equipment, including the addition of a new traveling wave tube, a low-noise exciter and a multi-mode seeker [29]. After a demonstration and validation period for each missile, the ERINT-1 was chosen over the MM system at the end of 1993.

The PATRIOT MM was to provide the PATRIOT weapon systems with increased guidance system accuracy that is needed against tactical ballistic missile, cruise missile, air-to-surface missiles, and low radar cross section (RCS) aircraft, including both rotary-wing and fixed-wing aircraft. The MM is a combination program of the mutli-mode seeker (MMS) (with improved warhead) and Improved Propulsion System (IPS) program upgrades [30].

The PATRIOT MMS combines an active, Ka-band seeker capability with the current semi-active C-band capability. It features an additional active guidance mode at Ka-band (33 to 35 GHz) to provide high gain, small beam-width, and low antenna sidelobes necessary to reflect stand-off jammers and to reduce miss distance, and an improved TVM guidance (front-end noise reduction from 12.5 db to 6.0 db) to improve performance against low observable targets. The MMS has been developed through the Multi-mode Seeker Demonstration Program conduced by the U.S. and Germany under the Extended Air Defense Memorandum of Agreement of May 1989. Raytheon is the prime contractor [30].

The demonstration and validation (pre-EMD) contract was awarded on July 24, 1989 for six MMSs, four flight test missiles, one preflight certification/White Sands Missile Range test analysis missile, and one guidance test facility missile. The demonstration/validation phase proceeded through hardware design, fabrication, assembly software design, code, integration and testing and was scheduled to conclude in 1992. The first guided launch for the MM occurred in April 1992. Three additional launches were accomplished, including a shot against a low-RCS tactical ballistic missile with a separating reentry vehicle (RV). Flight testing ended with a final launch in October 1993 [30].

STINGER (FIM-92)

The Stinger is a man-portable antiaircraft missile originally developed for the U.S. Army as a replacement for the Redeye system. General Dynamics (GD) is the Stinger's prime contractor. Three versions of the Stinger have been developed and fielded; the FIM-92A Basic the FIM-92B passive optical sensor technique (POST) and FIM-92C reprogramable microprocessor (RMP). All Stingers have passive infrared guidance that provides a fire-and-forget capability. The POST and RMP provide for capability in the ultraviolet wave band. The Stinger is different than the other air-defense missiles in our database in that it does not depend on a ground-based radar complex for any part of the missile guidance function. Instead, the missile is cued optically by its operator.

The Stinger system provides many advantages over the previous Redeye system it replaced. It has an all-aspect acquisition capability as opposed to the tail-chase-only capability of the Redeye. The Stinger also has a built-in identification friend or foe (IFF) capability, a critical additional capability for a man-portable missile. Constituent parts of a Stinger round include a disposable launch tube as well as the missile itself; the missile consists of guidance, propulsion, and warhead sections.

The Stinger had its roots in the Army's Advance Sensor Development program, which began in July 1965 with the award of a contract to GD. The primary purpose of this program was to study seeker technologies that would enable all-aspect engagement capabilities. The studies ended in 1970. The Redeye II concept was chosen over competing designs in February 1971; this marks Milestone I in our database. The Redeye II program office was established in January 1972; the missile was re-designated Stinger in March 1972. Milestone II approval was given by the Defense Systems Acquisition Review Council (DSARC) in May 1972; an EMD contract was awarded to GD the next month. The Critical Design Review (CDR) occurred in March 1973 [31].

The first guided launch of the Stinger was achieved in November 1973. The initial portion of the flight test program was the guided test vehicle (GTV) segment, which was performed by GD. This segment included 16 flights against point source and plume targets, including targets employing maneuver, tactical countermeasures and nose-aspect approaches. Technical problems encountered caused delays in flight testing; flight testing was halted in April 1974 and again in August of the same year. A solution to the technical problems encountered was verified during a January 1975 flight test. Additional design changes intended to lower Stinger acquisition costs were incorporated into the flight test program in FY 1975. The changes included relocating certain components from the missile round to the reusable grip-stock. The last GTV flight test occurred in July 1975 [31].

The Design Flight Test was conducted by the Army and began in July 1975 and continued until January 1976. In all 18 flights were accomplished. This represents a much higher launch-rate than achieved in the troubled GTV test segment. This test segment included the first Stinger launch from a man's shoulder and launches in West Germany with U.S. and West German personnel. The contractor prototype qualification test (PQT) began in February 1976 and ended in October 1976 with 32 flights accomplished. The government PQT/OT segment began in October 1976 and ended in April 1977. Included were 11 launches of environmental test rounds and 11 OT launches. Production Prototype Testing (PPT) included 18 flights occurring between July and November 1977 [7].

Figure C-3 presents Stinger Basic test phases over time and the launch rates associated with each phase. As in the case of other Army missile programs, we found no explicit mapping between the test segments and the usual DT&E and IOT&E test phases, so we created our own mapping, which is presented in Figure C-3.

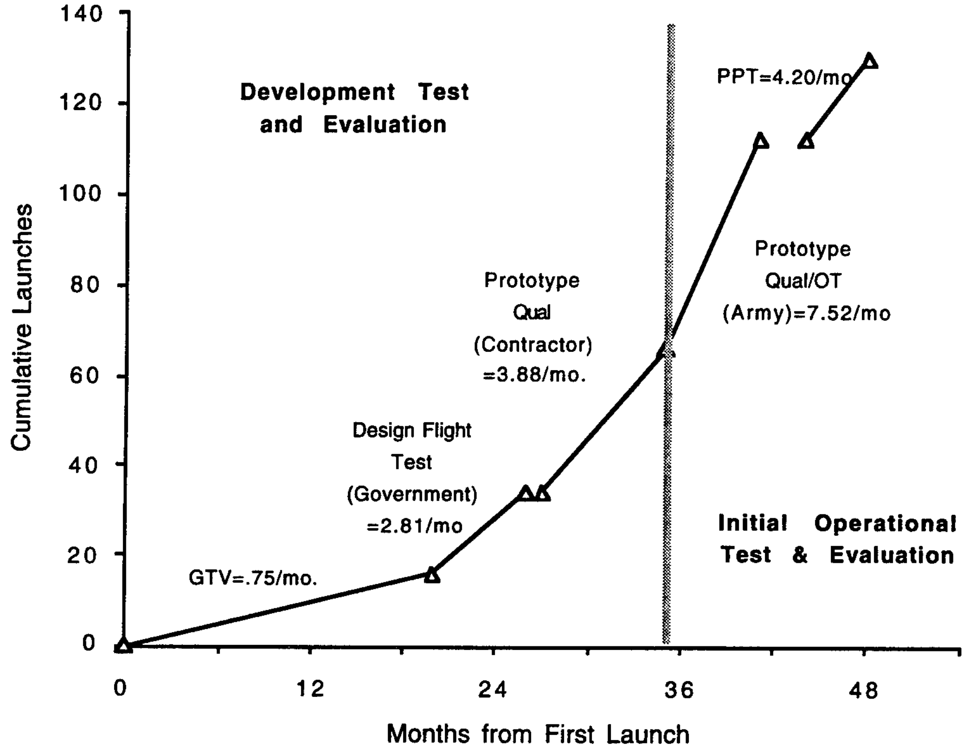

Figure C-3. Stinger Basic Flight Test Launches

In December 1977, one month after the PPT was completed, Milestone IIIA approval for low-rate production was given. A contract was awarded to GD for the first 258 production missiles in April 1978. The first production missile was delivered in December 1979. Milestone IIIB approval occurred in June 1978. The first full-rate production contract was a multi-year buy of 4,971 missiles covering fiscal years 1979-1981. The first delivery of these missiles was in February 1981. IOC was achieved in February 1981 when operational units in Europe received the first tactical hardware [31].

STANDARD MISSILE 2 (SM-2, RIM-66C/67B)

The Standard missile family consists of shipboard surface-to-air missiles that provide fleet air defense capabilities to the Navy. General Dynamic's Pomona Division was the original prime contractor on the Standard Missile. The Standard Missile 1 (SM-1) was developed in the mid-1960s and was produced in two versions, medium range (MR) and extended range (ER). The SM-1 was improved via multiple block upgrades through Block VI. Guidance for the SM-1 is provided by a semi-active radar seeker which homes in on targets illuminated by shipboard continuous-wave radar. The SM-2 series of missiles differs from the SM-1 series in that the semi-active terminal guidance is supplemented by mid-course guidance provided by an inertial reference system and ship-missile data link. The SM-2 also introduced fixed-scan monopulse guidance and a digital guidance computer to the Standard missile family; these and other SM-2 features were later included in the SM-1 Block VI. MR and ER versions of both missiles differ primarily in their propulsion systems; the MR has a single dual-thrust solid rocket motor while the ER has a two stage propulsion system with a dropable booster. The ER missiles are associated with the TERRIER shipboard weapons system while the MR missiles are associated with the TARTAR and AEGIS (SM-2 only) weapon systems [32].

The Standard missile is modular in design, allowing the commonality and growth flexibility to assure physical, functional, and operational compatibility with existing ships and those under construction. This modularity allows Standard missile to be fielded in MR and ER versions by addition of appropriate propulsion sections. Past and present Standard missiles include: SM-1 Block I to VI and SM-2 Block I to IV.

The SM-2 Block I was the first SM-2 design. The SM-2 Block I program began in early 1969 under a level-of-effort support contract. The Advanced Development phase began in July 1970 after completion of system definition. Through this pre-EMD program, four prototype missiles (FTRs 1 through 4) were designed and fabricated and two missiles were flight tested (FTRs 1 and 2) [33].

A formal Engineering Development contract (N00017-72-C2208) was signed in May 1972. This marks the beginning of EMD in our database. This contract called for the design, fabrication, and testing of 14 additional flight test missiles (FTRs 5 through 18). The contract also called for an ultimate development objective of an SM-2 production data package released to production (RTP) by October 1974. In September 1972 contractual go-ahead to include monopulse guidance was received. The program was suspended for four months from February to May 1974 due to the delay in FY74 funding approval by Congress. At that time, only the two missiles contracted for under the Advanced

Development contract had been tested. FTR-3 was flown in December 1972 (4 months late) and FTR-4 in September 1973 (11 months late) [34].

Program funding resumed in June 1974. In August 1974, GD proposed a contract modification, which was granted. The modification was to: (1) complete the FTR 3-18 program and RTP by October 1975 (one year later than specified in the original contract) and (2) design, fabricate, and support flight testing of an additional 36 missiles to be completed by February 1977.

FTR-5 was the first EMD missile and the first flight test article with monopulse guidance and thus was the first representative SM-2 missile; it was also the first AEGIS variant. FTR-5 was launched at White Sands Missile Range (WSMR) in December 1974, 31 months after development start; this marks first guided launch and DT&E start in our database. DT&E took place in two segments. The first was at WSMR and consisted of 14 launches, including AEGIS/MR and ER missiles with the last launch occurring in September 1976. The second segment (December 1976 to May 1977) included nine launches using the first AEGIS engineering development model (EDM-1) located on the USS *Norton Sound.* IOT&E also consisted of two segments. In the first segment (September 1976 to November 1976) ten ER missiles were launched from the USS *Wainwright* using the TERRIER missile defense system. The second segment was conducted on the *Norton Sound* with the AEGIS EDM-1 system; seven missiles were launched during July 1977. Two special high-altitude supersonic target (HAST) tests and an additional DT&E test were conducted in March 1978 and April 1978 [35 and 36]. Figure C-4 presents cumulative test launches over time for the SM-2 Block I program. Note that the launch rates are not averages but represent the slope coefficients of the regression lines. This is the case for all similar figures in Appendix C.

Of 50 SM-2 missiles procured for engineering development (excluding FTRs 1-4) 43 were used in flight testing. Of the remaining seven missiles, four were diverted to Pilot Production. The SM-2 Selected Acquisition Report (SAR) shows IOC occurring in September 1977. This indicates that missiles delivered under the development contract were considered to be the first operational missiles.

The first SM-2 production contract began in June 1976 with an award to GD for 22 pilot production missiles; the first pilot production missile was delivered in April 1978 [35]. This marks the first production delivery in our database [16]. The contract for 36 Initial Production missiles began in January 1976 with first delivery in February 1979. To maintain hardware commonality with SM-1 Block VI and at the same time to accommodate future large-scale SM-1 Block VI production, a major technological change was implemented to SM-2 Block I manufacturing in FY79 [33]. In all, there were six production lots (including Pilot Production) with the last being in FY81. The production rate reached its peak of 33 per month during the FY81 buy [35].

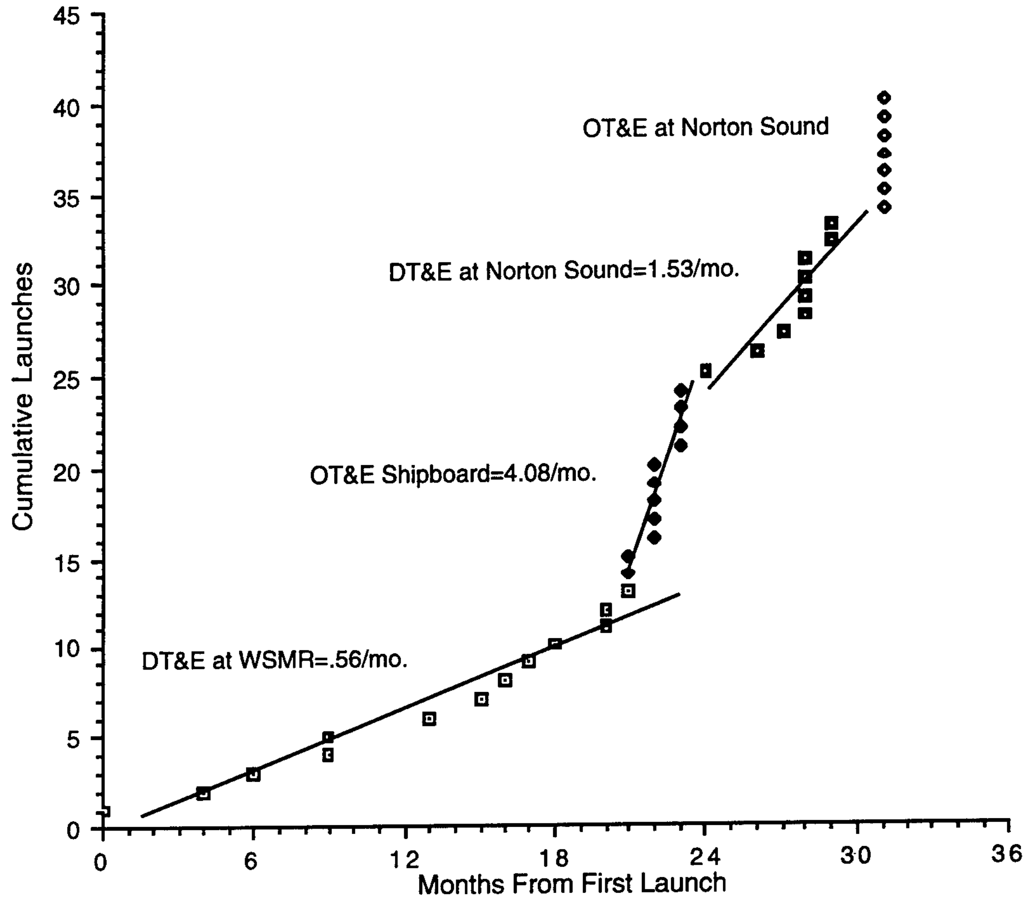

Figure C-4. SM-2 Block I Flight Test Launches

SPRINT AND SPARTAN (SAFEGUARD PROGRAM)

System Description

Safeguard was the anti-ballistic missile (ABM) system proposed by the Nixon administration as a replacement for the proposed Sentinel program. The original Sentinel proposal was quite ambitious, designed to protect both the civilian population and the deterrent forces. Safeguard, however, had more limited objectives. The Safeguard proposal emphasized protecting the Minuteman sites. Only light overall protection of the population would have been provided. After President Nixon's visit to Moscow, the United States and the Soviet Union agreed that deployment of the Safeguard system and its Soviet counterpart would be limited to two complexes in each country. In October 1975, Congress drastically cut funding for the system and later directed the Army to deactivate the system [37].

Safeguard would have employed two types of ABM defense—area defense and terminal defense. Two parts of the system are included in our study—the long-range Spartan missile and the short-range interceptor missile designated Sprint.

The area defense system is designed to intercept intercontinental ballistic missiles (ICBMs) and submarine-launched ballistic missiles (SLBMs) above the atmosphere at ranges of several hundred kilometers. A large, long-range radar called the Perimeter Acquisition Radar (PAR) detects and tracks missiles. The Spartan, a long-range missile, is launched to intercept the incoming missile. Spartan was a slightly enlarged version of the earlier Nike Zeus missile. It was a command-guided anti-missile missile powered by a three-stage solid propellant rocket. Because of the wide range of protection available from a single Spartan site, only 12 sites would have been necessary to protect almost all of the contiguous United States. The principal shortcoming of area defense is its potential to be disabled by very lightweight confusion devices or by a detonation outside the atmosphere [38].

Because of this limitation, terminal defense, a second line that would be activated after the effects of the confusion devices had been dissipated, was developed. It uses a small, very fast interceptor missile called Sprint. Sprint was a two-stage, solid-propellant, cone-shaped missile launched from an underground cell and intended for use as an anti-missile missile. The Sprint missile was operated with the Missile Site Radar (MSR) that sorts out the confusion devices and guides the Sprint to destroy the missile with its low-kiloton-range warhead. The Sprint missile was conical with a length of 27 feet and a base diameter of 4.4 feet. Its launch weight was approximately 7,600 pounds. A Sprint and an MSR can protect only a small area and must be located near that area [38].

Development Process

Sprint

In March 1963, the Army announced that the Orlando Division of Martin Marietta Corporation had won a design competition to develop the Sprint, and the contract was signed in May of that year. The rocket motors were from Hercules, Inc., and the guidance and control section was from Honeywell, Inc., and Western Electric.

Originally, Sprint was supposed to have been deployed by 1970, a relatively ambitious schedule. In November 1965, the first guided Sprint flight was successfully carried out at White Sands Missile Range, less than 3 years after the first design study. Eventually, the pressure for rapid development lessened, and the schedule was redesigned to require limited deployment in 1974-75. The prototype MSR began radiating power in September 1968. Local targets were first tracked with the MSR software in July 1969. Two ICBMs launched from Vandenberg Air Force Base, California, were tracked in December 1969. Development testing for the Sprint was completed in August 1970 [37].

Operational testing began in October 1970. In the first system test against an actual target, in December 1970, the Sprint successfully intercepted an ICBM target nose cone. In the first system test against a sea-launched missile, in May 1971, a Sprint intercepted a Polaris warhead over the Pacific. The first series of sixteen Sprint system tests ended in the autumn of 1971, with 12 complete successes, 2 partial successes, and 2 failures. A second series, from mid-1971 to the end of 1973, had 29 complete successes out of 32 tests. Deployment of Sprint missiles began in June 1974 [37]. This marks IOC in our database.

A $1.5 million contract definition study for an improved version, Sprint II, was begun by Martin Marietta in May 1971. The goals for the improved version included greater accuracy, greater maneuvering capacity, increased reliability, hardening and strengthening against nuclear blast and maneuver stress, and a faster launch process. In October 1971 a $2.5 million advanced design contract was awarded. In May 1972, a $168 million contract for development and flight testing of the prototype interceptor was awarded to Martin Marietta. Sprint II work was terminated in August 1975 due to funding reductions.

Spartan

Western Electric Company was the original prime contractor for Spartan, with Bell Telephone Laboratories having research and development responsibility. In March of 1965, Bell Labs was told to proceed with Phases I and II of research and development, which consisted of system definition, development planning, and preliminary design. In October 1965, McDonnell Douglas assumed responsibility for missile development. This marks EMD start in our database. The rocket motors were from Thiokol Chemical Corporation, and the missile-based guidance was from Honeywell, Inc.

The first successful launch of the Spartan missile occurred from a concrete cell in March 1968. In March 1970, the Army completed Spartan development testing, with 11 completely successful test firings, 2 partially successful firings, and 2 failures. Operational testing began the next month. In August 1970, the first operational intercept test of Spartan was successfully completed, with the Spartan intercepting a Minuteman I modified test vehicle. The operational testing involved 20 launches from Meck Island [37].

A modified Spartan missile, designated Improved Spartan, was designed to be faster and to have greater acceleration than the original, to deal with the threat from SLBMs and low-trajectory ICBMs. The Spartan was phased out after the decision was made to deactivate the Safeguard system.

SAFEGUARD System

In early 1970, integration of all major Safeguard system components except the PAR began. The first system test used a Spartan missile and was conducted on April 14, 1970. There were 42 successful system tests, two partially successful tests, and five failures by the end of 1973. The process of installing the Spartan and Sprint launch equipment was completed in August 1974.

A radar similar to the PAR became operational at Eglin AFB in late 1968, and a limited engineering development model of the PAR was constructed at General Electric during 1969. In August 1972, installation and testing of tactical equipment began at the Perimeter Acquisition Radar (PAR). In August 1973, the PAR successfully accomplished initial live satellite tracking. In August 1974, PAR Operations Acceptance tests were completed.

The installation and testing of tactical equipment at the MSR began in January 1973, and by December of that year, there was successful live tracking of a satellite. In June 1974, autonomous MSR site tests were completed.

The entire Safeguard system was delivered by the contractor to the Army in October 1974, and it achieved IOC in April 1975, with 28 Sprint and 8 Spartan missiles. There were 47 totally successful tests at Kwajalein out of 54 total. Full operational capability was achieved in October 1975 with 70 Sprints and 30 Spartans.

Because of the ABM Treaty, the only places Sprint missiles could be fired were White Sands and Kwajalein. Congress decided in October 1975 to cut funds for the Safeguard system severely, and, later that same month, ordered the system deactivated.

ERINT-1

The ERINT-1 (ERINT stands for Extended Range Interceptor) missile is a hit-to-kill interceptor that features high frequency (ka band) radar terminal guidance. The interceptor is intended to provide underlay defense against tactical missiles at middle to low altitudes. When it is fielded, the ERINT-1 is to be compatible with current PATRIOT fire units; the smaller ERINT-1 will allow 16 missiles to a launcher as opposed to the current 4 per launcher for the PATRIOT missile.

The ERINT-1 started EMD in October 1994, after the completion of a pre-EMD prototype program [23]. The ERINT-1 is the culmination of a series of Strategic Defense Initiative Organization demonstration programs beginning in the early 1980s. The programs included the SRHIT (Small Radar Homing Interceptor Technology), FLAGE (Flexible Light-Weight Guided Experiment), and ERINT.

The SRHIT began flight hardware development with a contract to Vought in December 1982. The purpose of the program was to demonstrate the principals of endoatmospheric hit-to-kill using radar homing against simulated reentry vehicles. The context was as a point defense of Minuteman missile silos. Many of the basic concepts incorporated into the ERINT-1 were introduced in the SRHIT. These include roll-stabilization, a solid propellant attitude control system and terminal guidance via a millimeter wave terminal seeker. The SRHIT was provided with mid-course guidance and terminal guidance activation and cueing through a data link [39].

The first SRHIT launch was accomplished in January 1984 at WSMR; this was a non-guided launch to test launcher and booster performance. This was followed by flights in March and November 1984 to test the vehicle's maneuver ability and attitude control concept. The first guided flight (GTV-1) was not accomplished until January 1986; the target for this flight was an aluminum sphere suspended from a balloon [39].

In March 1986 the program was renamed FLAGE due to changes in scope, mission and funding. The primary objective of FLAGE was to quantify miss distances and validate simulation modeling of endoatmospheric missile intercepts through continued flight testing. The second guided flight occurred in April 1986 and was a repeat of the first. The third and fourth launches were performed with an air-launched booster and Lance missile as targets in June 1986 and May 1987. Having completed the launches successfully, the FLAGE program was brought to a close in September 1987.

Concurrent with the FLAGE program were studies of the ERINT concept, which was to build on the information and hardware produced by the SRHIT and FLAGE programs. Additional areas to be explored included a lethality enhancer, guidance elements, heat-shield/shroud and attitude control system. In April 1987 Vought was awarded a three-year, $80 million contract for ERINT development. This effort was stretched-out and pared slightly in October 1987. A much larger realignment occurred with the alteration of the contract in November 1989; the P0020 modification doubled the value of the contract and the government restructured the program directing Vought to employ ERINT-1 pre-prototype hardware in flight testing. This marks the beginning of Advanced Development for ERINT-1 in our database. Another major contract modification occurred in October 1991, which resulted in added funding and a schedule that was again stretched. Figure C-5 presents the evolution of ERINT contract pricing as well as funding levels for the Vought contract [39].

Differences between the ERINT and the FLAGE were largely a result of increasing the effective altitude of the missile. Large angle-of-attack maneuvers in the upper bounds of the flight envelope result in larger boresight errors compared with FLAGE. In order to insure target kills, a lethality enhancement was added to ERINT. A larger rocket motor was required to reach higher altitudes and to compensate for the additional weight of the enhanced lethality. The transmitter power of the radar seeker was doubled and ranging capability was added. Because the launch weight of the missile was increased substantially (from 505 pounds to 1,214 pounds), more control authority was demanded from the ACS. The ERINT design was not finalized and no ERINT hardware was built before the redirection of the program to ERINT-1.

Although functionally similar to ERINT, ERINT-1 represented a major change in physical configuration. To allow for its integration into the PATRIOT missile system, major repackaging of subsystems and materials changes were required. Motor diameter was reduced from 15 to 10 inches while the forebody diameter was increased form nine to ten inches. Missile launch weight decreased from 1,214 pounds to 670 pounds.

The first ERINT-1 Controlled Test Flight (CTF) occurred in June 1992 at WSMR. A second CTF was accomplished in August 1992. The first Guided Test Flight (GTF) occurred in June 1993, 43 months after development start. This marks the first guided-launch for ERINT advanced development in our database. The target for this test was a Lance TBM. Three additional GTFs were accomplished in November 1993, February 1994, and June 1994 [40 and 41].

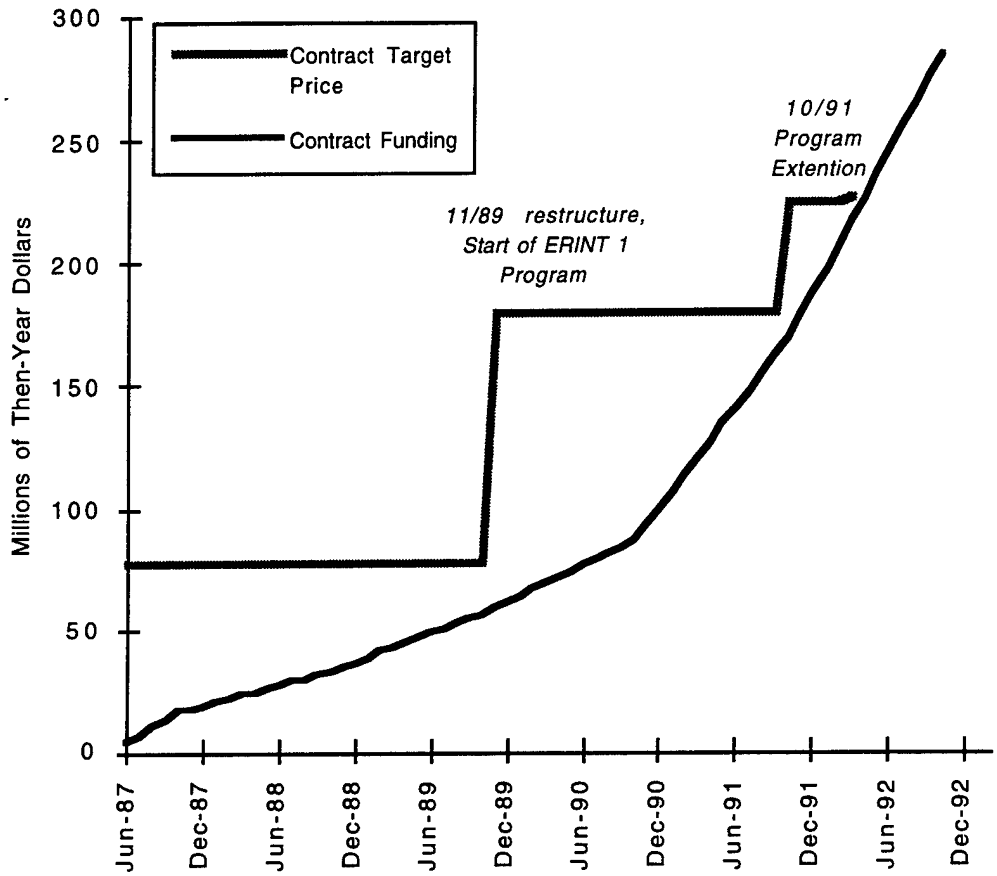

Figure C-5. ERINT Contract Price and Funding

SPARROW F (AIM-7F)

The Sparrow F program was distinguished by technical problems that involved several redesign efforts, delays in flight testing, and increases in the number of test missiles launched. These problems resulted in the postponement of production go-ahead. Development of the Sparrow F entailed the replacement of the Sparrow E's guidance section vacuum-tube circuits with solid-state circuits and incorporating a larger rocket motor and warhead. The original development contract (N00019-67-C-0019) called for the development and delivery of 6 XAIM-7F and 28 YAIM-7F development missiles [42 and 43].

Technical difficulties became evident during flight tests. Seven launches were accomplished during the initial CDT phase before testing came to a halt and a major redesign effort was initiated. After a 13-month pause in testing, a combined CDT/NTE test program resumed with 11 more launches performed with missiles drawn from the original development lot.

An additional 65 and 29 development missiles were procured under March 1968 and September 1970 pilot production contracts (N00019-68-C-0386 and N00019-71-C-0024), respectively. Of these missiles, 31 were launched during the remaining NTE testing and 25 were launched during the first OPEVAL. Poor missile performance during the first OPEVAL resulted in a second OPEVAL consisting of 25 missile launches. The missiles were supplied by a June 1972 pilot production contract (N00019-72-C-0583) for 50 Navy and 50 Air Force missiles. A substantial number of Sparrow F test missiles were also used in support of F-14 and F-15 aircraft development. A fly-before-buy acquisition strategy meant that DSARC III approval for the first full production contract (FY1975) did not occur until one month after the end of OPEVAL in October 1974. The unusually long interval of 94 months between the first launch of an EMD missile and the first production delivery was a result of delays in the test program, the large number of pre-production missiles built and tested (99 launches in all), and the lack of concurrency between development and production [11 and 42].

Figure C-6 shows the build-up of test launch experience for the Sparrow F program. Time-series data for the second OPEVAL were not available. Evident is the 13-month delay between CDT and NTE, which was the result of the first redesign effort. The pause in the NTE after the 33rd month was a result of a second redesign. There was also a substantial gap between the end of the first unsuccessful OPEVAL and the beginning of the second. The Sparrow F OPEVAL program was distinguished by the use of multiple test ranges.

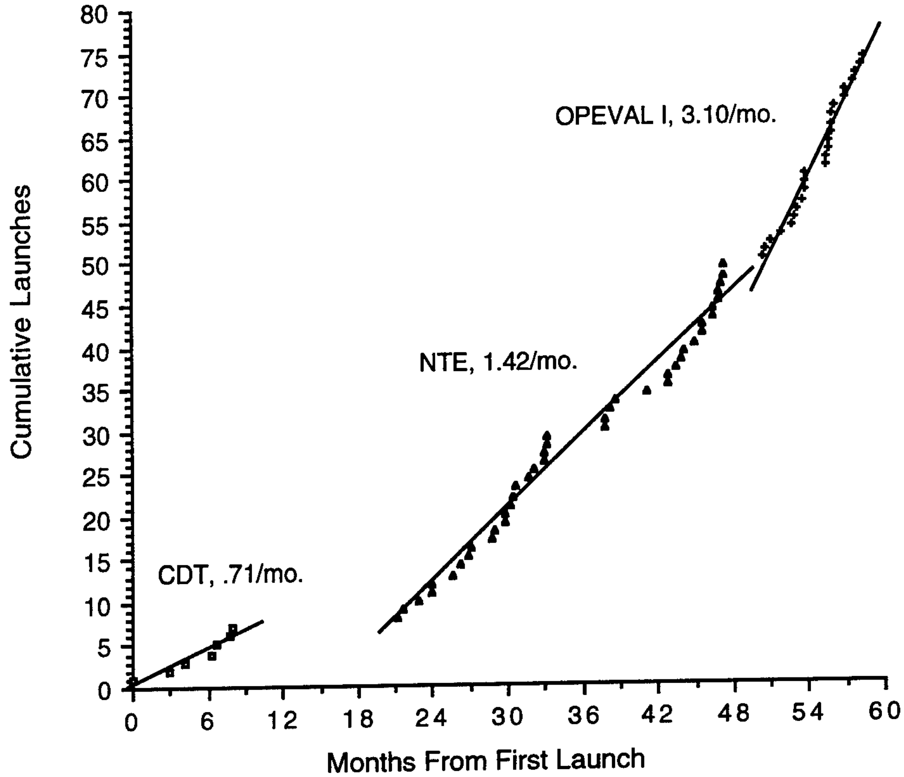

Figure C-6. Sparrow F Test Launches

SPARROW M (AIM-7M)

The Sparrow M program included the development of a monopulse seeker with digital signal processing and a new active fuse. A competitive prototype phase was employed as a mechanism to choose between the Raytheon and the General Dynamics seeker designs. The contractors built five missiles each and a total of five launches were accomplished. The Raytheon design was eventually selected, and EMD go-ahead occurred in April 1978. Forty-four test missiles were procured under the EMD contract. Thirteen launches were accomplished during CTE. JTE consisted of 22 launches [44].

The Sparrow M program was distinguished by a high launch-rate relative to other air-to-air programs. The surface-launched version of the Sparrow M, the RIM-7M, was tested in a combined program; the use of surface ships as launch platforms facilitated a high firing-rate. During one nine-day period, six launches were accomplished, five of which were from a surface ship [11]. The small number of test missiles required, the high launch-rate, and the lack of technical problems were responsible for the relatively short period from first guided launch to first production delivery.

SIDEWINDER L (AIM-9L)

Sidewinder L development included a new all-aspect seeker with added sensitivity. We considered the Sidewinder L development as having a pre-EMD prototype program despite the high degree of continuity between the prototype program and the EMD program. The prototype program began in June 1971, when go-ahead was given to the Naval Weapons Center to design and build engineering test missiles [46].

Eleven engineering test missiles were launched between April 1972 and July 1973. The award of a development contract to Raytheon for 26 development test missiles in July 1972 was considered the start of EMD. The first guided launch of an EMD missile occurred in October 1973. The scope of the EMD contract was expanded to include 126 test missiles, 46 of which were used in support of F-15 aircraft testing. The expansion was a result of program restructuring due to technical difficulties, the need for more testing, and the elimination of concurrency.

Missile test launches during EMD included 10 in CTE, 20 in JTE, and 30 in IOT&E/OPEVAL. The Sidewinder L program followed a fly-before-buy acquisition strategy. DSARC III production go-ahead did not occur until January 1976, one month after the completion of IOT&E/OPEVAL. Operational evaluation of the Sidewinder L included Air Force participation, so the test program was designated as OPEVAL/IOT&E. Because of the overlap between the end of JTE and the start of OPEVAL/IOT&E, we report the two phases as a combined program in Table II-11 of the main text. Two test ranges were used in support of JTE/OPEVAL/IOT&E.

SIDEWINDER M (AIM-9M)

Sidewinder M development included a new seeker for better performance against countermeasures and infrared background, a low-smoke motor, and a closed-circuit cooler to reduce logistics problems. Only a minimal amount of data were collected for the Sidewinder M program.

PHOENIX A (AIM-54A)

The Phoenix A program was unusual because missile development was concurrent with development of the launch platform (the F-111B and, later, the F-14A aircraft) and fire-control system (AWG-9). The program schedule was affected by the change in the intended launch platform from the F-111B to the F-14A. The original Hughes Aircraft research and development effort was performed mainly with F-111B aircraft. Prior to the availability of F-111Bs, A-5 test-bed aircraft were used as launch platforms. Out of 37 missiles delivered from the original development contract (N0W 63-0379), 26 were air-launched during CDT. Time-series data were collected for the original Phoenix A EMD CDT. This data are presented graphically in Figure C-7. The regression lines characterize two distinct portions of the CDT effort. Again, the rates reflect regression slope coefficients. The Phoenix A CDT included multiple launch events, which are evident on the graph as multiple points on a given date [47].

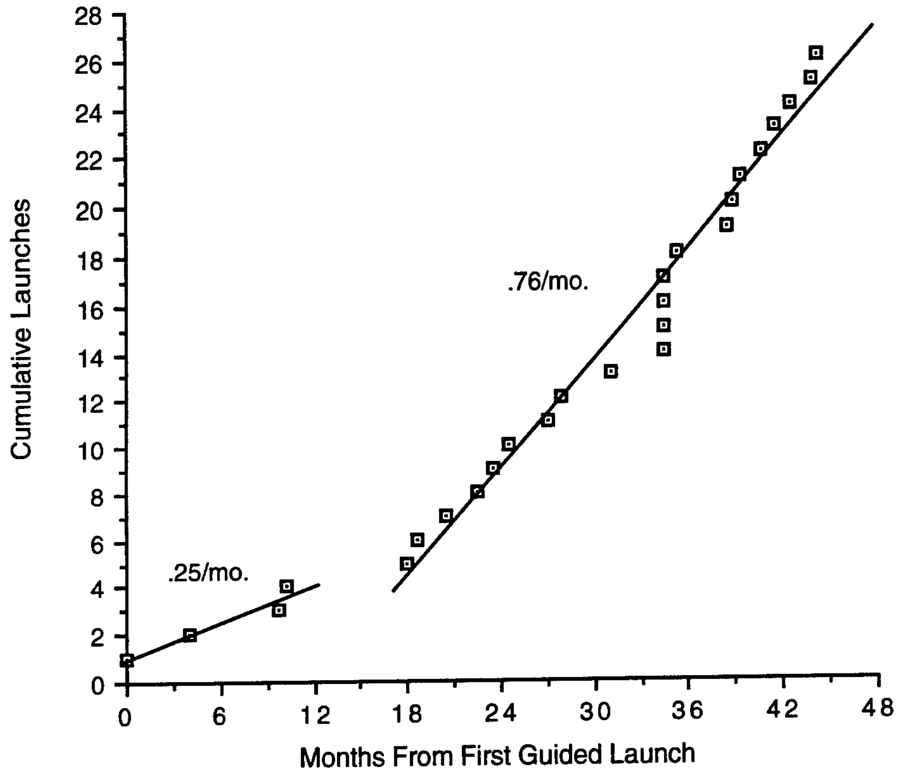

Figure C-7. Phoenix A Initial CDT Launches

The F-111B program was canceled in July 1968, and the F-14A entered EMD in January 1969. NTE of the Phoenix was delayed from its planned start date in the fourth quarter of 1969. CDT launches from the F-111B aircraft continued under the original contract until December 1969. Additional CDT launches were performed as a part of the test prototype/value engineering (TP/VE) missile contract (N00019-68C-0295), under which 16 TP and 10 VE missiles were delivered, and the F-14 separation and test (SAT) contract (N00019-69C-0633), under which 9 VE missiles and 22 SAT missiles were delivered. Twenty-seven CDT launches were accomplished between March 1970 and October 1973 [11].

A major goal of the two contracts was to retain the development team at Hughes during the gap between F-111B cancellation and availability of F-14 test aircraft. The first F-14 was made available for missile testing in January 1972. Sixty-nine additional test missiles were procured under an FY71 pilot production contract; 68 of the first full-production lot (FY72) of 240 missiles were also used for test purposes. Long-lead release for the FY72 lot occurred in December 1970. The first missile from this lot was delivered in March 1973. NTE started in June 1973 and continued until June 1974. OPEVAL occurred between August 1974 and July 1976. The large amount of concurrency between production and the last phases of the test program was facilitated by the large number of test launches accomplished under the CDT program, which, in turn, was a result of the cancellation of the F-111B.

PHOENIX C (AIM-54C)

The Phoenix C was a modification of the Phoenix A in which digital electronics replaced the analog components of the earlier missile. Fifteen engineering and development model (EDM) missiles were built under the EMD contract. Ten of these missiles were launched during the contractor test phase of the program. Figure C-8 graphically presents these launches. Thirty additional test missiles were procured under a pilot production contract. These missiles were used during NTE and OPEVAL. NTE commenced in May 1982 and was completed in November with the launch of six missiles. OPEVAL ran from March 1983 through June 1984 and consisted of fifteen missile launches. Considerable concurrency existed between development and production. The first delivery of a production missile occurring in August 1982. The build-up to rate production was slow; the first three production lots contained less than 100 missiles. IOC was not achieved until December 1986.

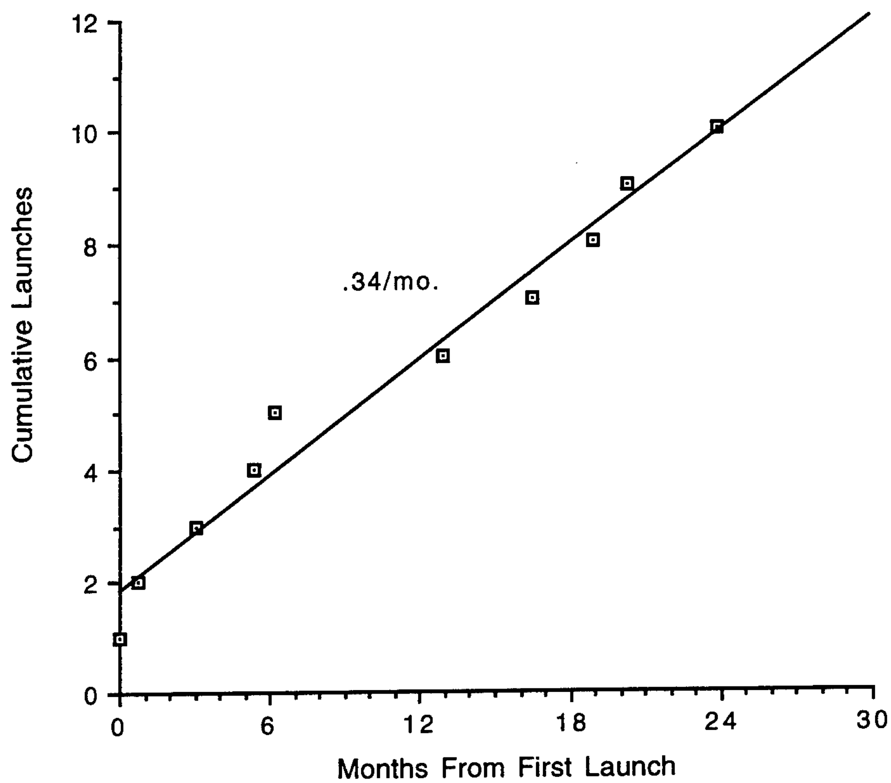

Figure C-8. Phoenix C CDT Launches

AMRAAM (AIM-120A)

The Advanced Medium-Range Air-to-Air Missile (AMRAAM) is the only air-to-air missile in our sample where the Air Force was the lead service. AIM-120 development included a competitive prototype program in which Hughes and Raytheon built 16 missiles each. Five Raytheon and three Hughes missiles were launched. Following the eight launches and other testing, Hughes was awarded the EMD contract. Three prototype missiles were launched in the early part of EMD. Under the EMD contact, Hughes built 122 test missiles, 91 of which were used in combined DT&E/IOT&E launch testing [48].

Considerable concurrency was built into the program with long-lead release for the first production lot occurring after 19 test launches. Figure C-9 presents available data on the AMRAAM DT&E/IOT&E program. The regression line represents the sustained rate achieved after the first three launches. This differs substantially from the rate calculated when launch experience from the beginning of the program is included. The AMRAAM test program also included multiple launches. The majority of AMRAAM launch testing took place at three test sites; a small number of additional launches took place at a fourth.

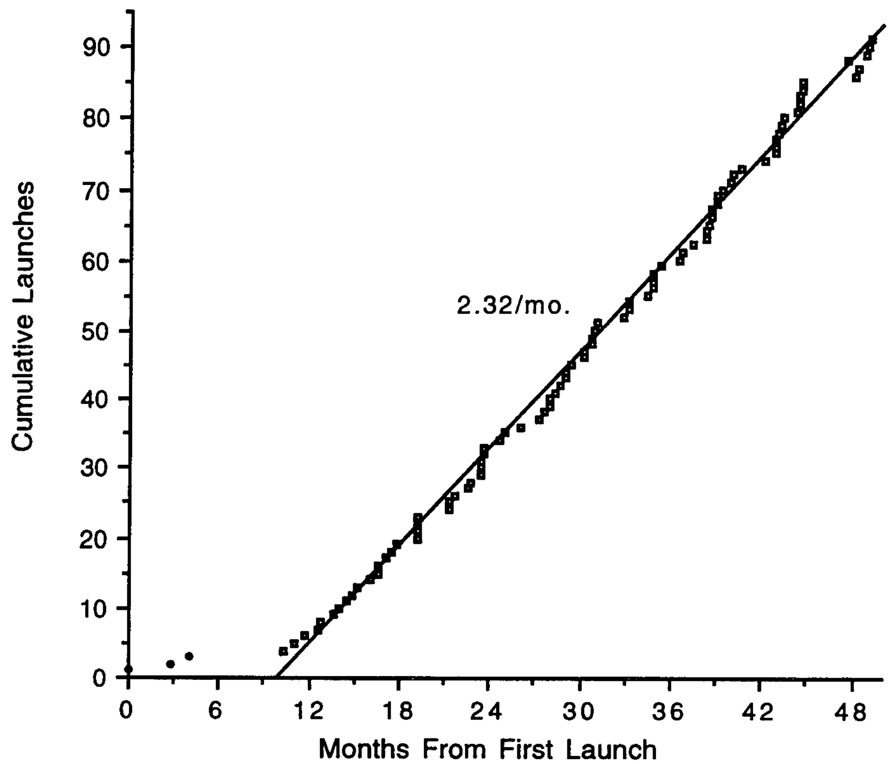

Figure C-9. AMRAAM DT&E/IOT&E Launches

MAVERICK EO (AGM-65A)

The Maverick A electro-optical (EO) is the only missile in our sample developed and produced under the total package procurement acquisition concept. The original EMD contract contained options for three production buys. Ninety-one test missiles were delivered under the EMD portion of the contract. Fifteen were launched during Category I testing and 37 were launched during Category II testing. Fourteen EMD follow-on development missiles were also launched after the completion of Category II testing. The launch rate achieved for Maverick A Category II testing is by far the highest for any of our programs. Figure C-10 graphically presents Maverick A Category I and II testing. There was very little concurrency in the Maverick A program; the first production option was exercised in July 1971, one month before Category II testing was complete [49].

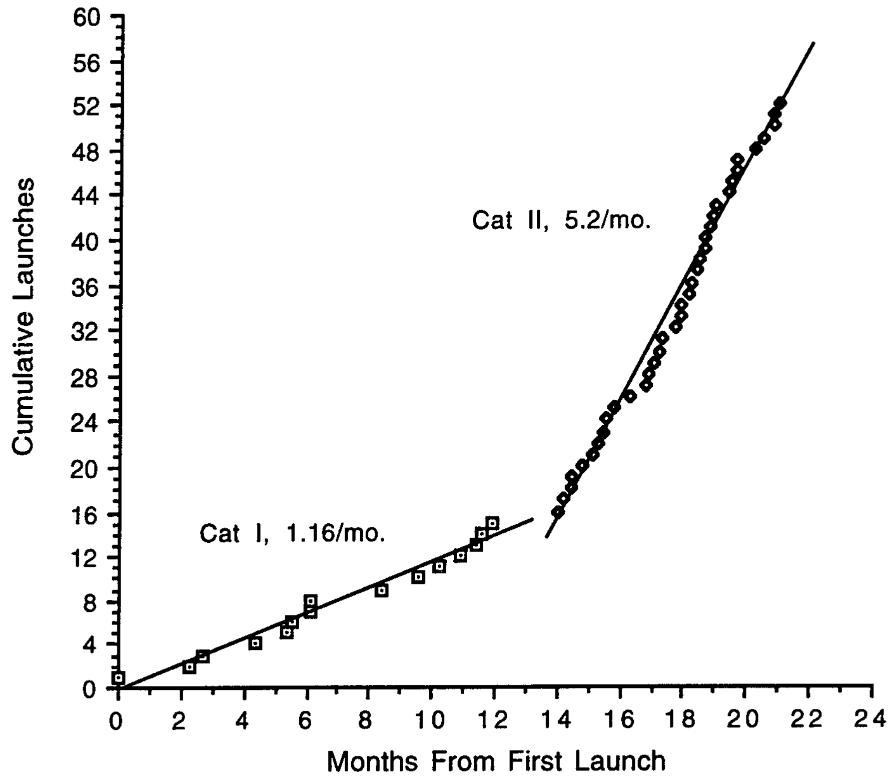

Figure C-10. Maverick EO Category I and II Launches

MAVERICK IIR (AGM-65D)

The longest prototype effort in our sample is associated with the Maverick D imaging infrared (IIR) Maverick prototype. The milestones reported for this missile are related to the IIR Free-Flight Demonstration for which eight prototype missiles were fabricated. Four of these were used in captive-carry flight testing and four were air-launched. The 18-month period from the start of the prototype program to the first launch of a prototype missile is typical. The prototype launches were completed by the end of 1975. No competitive fly-off was associated with the IIR Maverick. An advanced development contract that started in June 1972 included the design and fabrication of captive-flight test articles. Captive-flight testing started in mid-1973 and continued after the end of the free-flight program until mid-1978. A total of 790 flight-hours of captive testing was completed prior to the award of the EMD contract. The IIR Maverick pre-EMD effort is unusual in the long period of time between the prototype launch program and the start of EMD. This time period was taken up by an extended captive-flight program encompassing tests in various operational environments and studies on producibility and cost. Thirty-three test missiles were delivered under the EMD contract, 26 of which were launched during combined DT&E/IOT&E.

Figure C-11 graphically presents Maverick D DT&E and IOT&E testing. Although DT&E/IOT&E was a combined program, 8 of the 12 IOT&E launches occurred after the end of the DT&E program. In estimating the regression lines in Figure C-11, we considered IOT&E as consisting of the last 8 launches. Long-lead release for the first production contract occurred in April 1982, three months before the end of IOT&E.

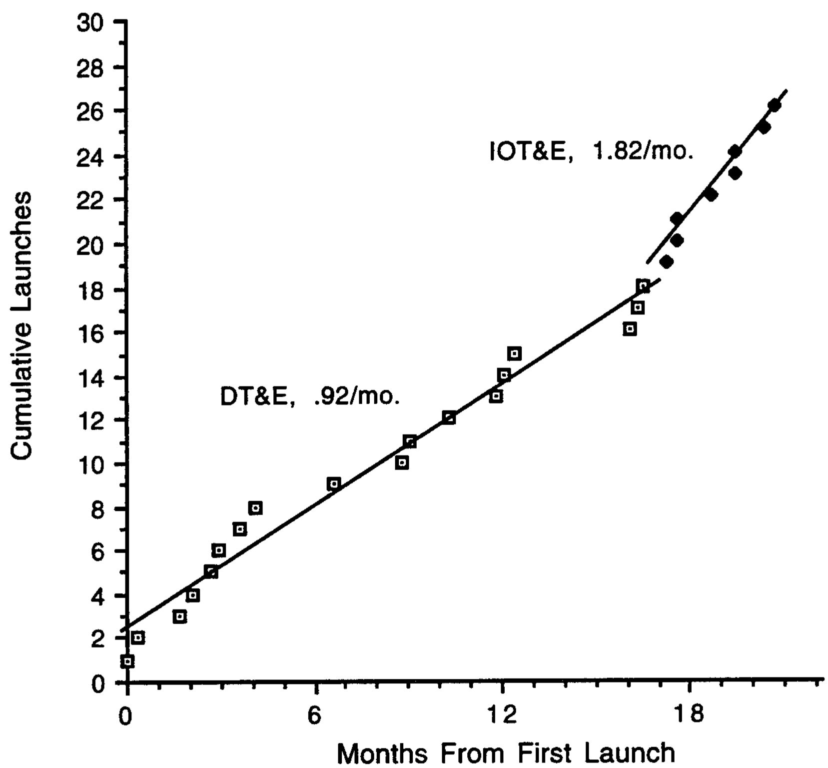

Figure C-11. Maverick IIR DT&E/IOT&E Launches

SHORT-RANGE ATTACK MISSILE (AGM-69A SRAM)

Although the AGM-69A short-range attack missile (SRAM) is a strategic missile, its relatively short range and the requirement that it be launched from a fighter-sized aircraft (the FB-111) aligns it with a tactical air-to-surface missile, albeit a large and sophisticated one. The SRAM took a longer time to first flight than any other air-to-surface system in our sample. Development problems with the SRAM were somewhat different than those for the other missiles in our sample because they were a result of technological push in the propulsion system as opposed to the guidance system. The AGM-69 was first test-launched from a B-52 aircraft, and test launches were made from FB-111 aircraft shortly thereafter. B-52 and FB-111 Category I and Category II tests were completed under the EMD flight test program in which 38 test launches were accomplished. Figure C-12 presents data on the AGM-69A test program.

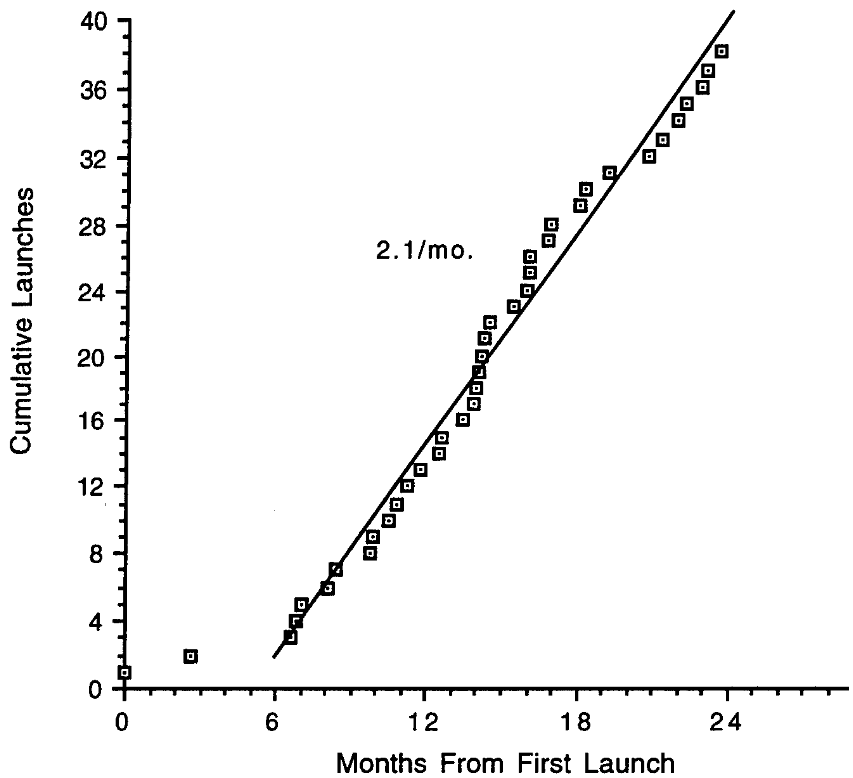

Figure C-12. SRAM Category I and II Launches

Although Category I and II tests were serial for each aircraft type, the test phases still overlapped, so we treated them as a combined program. The regression line represents the sustained rate achieved after the first two launches. Long-lead release for the first production lot was given in June 1970, 13 months before the end of Category II testing, making the AGM-69 a concurrent program [50 and 51].

HARPOON (AGM-84A)

The AGM-84A Harpoon is an example of a Navy missile program where there was not a clear break between the pre-EMD prototype effort and the EMD program. The Harpoon development program consisted of three phases: the design phase (N00019-71-C-0453), comprising the pre-EMD prototype program; the weapons system development (WSD) phase (N00019-74-C-0041), which was the primary EMD effort; and the pilot production phase (N00019-75-C-0070 and N00019-76-C-0052), which supported development through OPEVAL. As a part of the design phase, 12 prototype missiles were built, 9 of which were launched.

Although the WSD contract was not signed until June 1973, engineering go-ahead occurred in September 1972. We considered this date to be EMD start. Three prototype missiles were launched as a part of the WSD program. The first development missile was launched in March 1974. In all, 40 development missiles were delivered under the WSD contract. Of these, 15 were launched during CTE and 18 were launched during NTE. Thirty-three of the 100 missiles delivered under the pilot production lot were launched during OPEVAL. Due to performance deficiencies, the OPEVAL program was suspended for about seven months. As the Harpoon had variants that were ship- and submarine-launched, a significant number of test launches were performed from platforms other than aircraft [52].

Figure C-13 presents all phases of the Harpoon's test program, excluding OPEVAL.

Note the three prototype missiles tested during EMD. Also unusual is the continuity between the CTE and NTE programs. Note that months from first launch are based on the first prototype launch. Go-ahead for the initial production buy of 80 missiles occurred in January 1981, 7 months before the start of NTE. Long-lead release for the initial production lot occurred in June 1975, at the end of NTE but before the start of OPEVAL, making the AGM-84 a concurrent program.

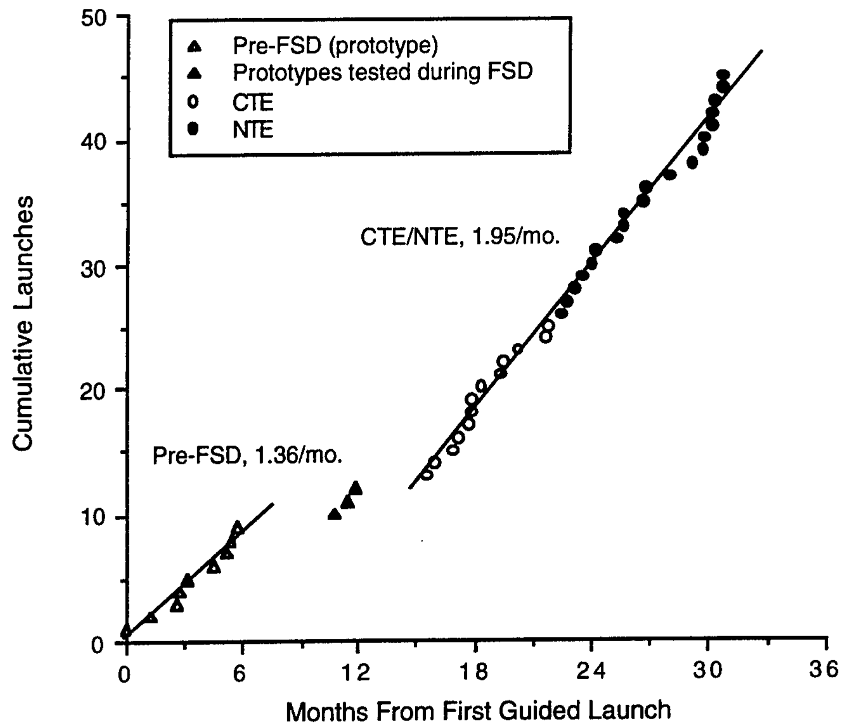

Figure C-13. Harpoon DT&E Launches

AIR-LAUNCHED CRUISE MISSILE (AGM-86B ALCM)

The AGM-86B air-launched cruise missile (ALCM) program presented a problem for our classification. We considered the AGM-86A a prototype of the AGM-86B as opposed to classifying the AGM-86B as a modification of the AGM-86A. We did this because the AGM-86A was never an operational missile; only seven AGM-86As were ever built, six of which were launched during advanced development, three of these on guided flights. The AGM-86A evolved from the Air Force/Boeing subsonic-cruise armed decoy (SCAD) advanced development program, which was canceled in July 1973 and resurrected in February 1974 as the ALCM advanced development program. Changes from the SCAD to the AGM-86A design were minor. Concurrent with ALCM advanced development was the development of the Navy's sea-launched cruise missile (SLCM). The ALCM and SLCM share common components, including guidance system, propulsion system and warhead. The Navy selected the propulsion contractor in May 1975 and the guidance system contractor in October 1975. The first guided flight of the SLCM prototype was in June 1976, three months ahead of the AGM-86A. In all, 16 SLCM launches were made during advanced development.

With the January 1977 DSARC II decision for the ALCM and SLCM to enter EMD, the ALCM's mission was changed to include a much longer range (1,500 nautical miles, verses 650 nautical miles). This change meant that the AGM-86B would have an essentially new airframe design and an increase in gross weight of over 1,000 pounds, making the AGM-86B program unusual among missile developments—the airframe was a major development item, but the guidance system was essentially off-the-shelf. Also unusual was the conduct of a fly-off competition during EMD [53].

In February 1978, EMD contracts were awarded to Boeing for development of the AGM-86B and to General Dynamics for development of the AGM-109, an air-launched derivative of the SLCM. The fly-off consisted of ten guided launches for each missile design. In March 1980, Boeing was chosen as the sole-source producer, and procurement of the first production lot of 225 missiles was approved at a DSARC III meeting in April. Development flight testing continued with 11 follow-on launches, which were completed in April 1981. Figure C-14 depicts both stages of AGM-86B flight testing.

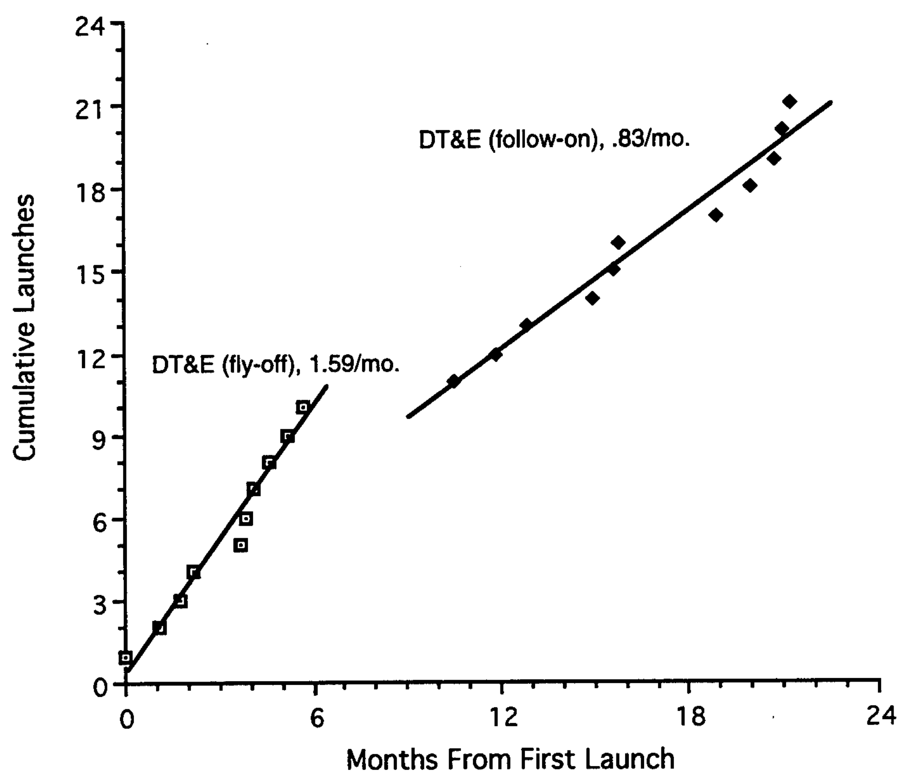

Figure C-14. ALCM DT&E Launches

Unusual is the decrease in launch rate from the fly-off program to the remaining DT&E flights. The higher test rate in the earlier part of the program may have been prompted by pressures to choose a production source as quickly as possible.

HIGH-SPEED ANTI-RADIATION MISSILE (AGM-88A HARM)

The AGM-88A high-speed anti-radiation missile (HARM) development program consisted of four phases. Phase 0 and Phase 1 comprised the pre-EMD prototype program, Phase II was the initial EMD effort, and Phase III supported development from NTE through OPEVAL/IOT&E. The Phase 0 contract (N00019-74-C-0410) was awarded in May 1974 and contained options for the remaining development phases.

The first HARM prototype launch occurred in January 1976; this was not a fully guided missile, but an aerodynamic flight test vehicle. The first prototype guided-missile was launched in October 1976. In all, 16 Phase I missiles were delivered and 9 pre-EMD launches were accomplished. Go-ahead for Phase II was given in September 1977, although a formal contract was not signed until August 1978. In our database, September 1977 is considered to be EMD start. Twenty-seven test missiles were delivered under Phase II, 18 of which were launched during CTE testing. Forty-five missiles were delivered during phase III, 40 of which were launched during NTE, OPEVAL, and IOT&E testing. The Air Force participated in this later testing and multiple test sites were employed [54].

Figure C-15 presents all phases of the AGM-88A's test program. Go-ahead for the initial production buy of 80 missiles occurred in January 1981, 7 months before the start of NTE.

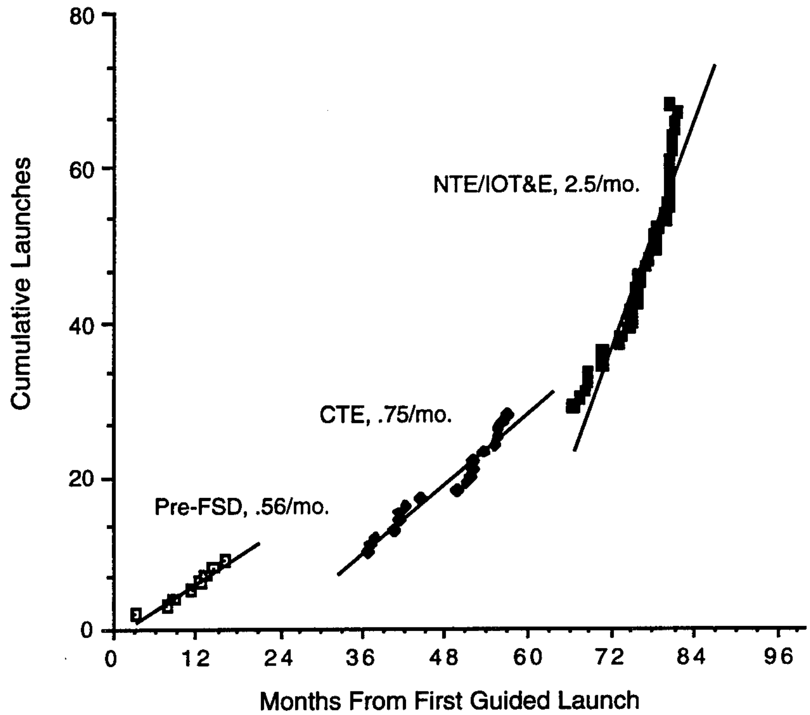

Figure C-15. AGM-88A Test Launches

HELLFIRE (AGM-114A)

The AGM-114 Hellfire differs in many ways from the rest of the missiles in our sample. It is by far the lightest air-to-surface missile, it is the only missile with laser guidance, it is the only missile whose primary launch platform is a helicopter (the AH-64), and it is the only air-launched missile developed by the Army.

Unlike other missiles, the guidance system and missile air vehicle had two separate prime contractors, Martin Marietta and Rockwell International. Because we consider the guidance system the pacing component, we measured all intervals from the start of Martin Marrietta's contract, which started after the Rockwell effort.

The Hellfire also differs from the other programs in that a comparatively large number of test missiles were procured and launched. The AGM-114's development program took much longer than any other air-to-surface missile. The target acquisition system associated with the AH-64/Hellfire was developed in parallel with the missile. The delayed availability of AH-64 launch platforms negatively affected the missile program's schedule. Because the AGM-114 is an outlier when compared with the rest of the programs in our sample, and because the data collected were relatively limited, it does not figure largely in our analyses.

APPENDIX D

OTHER REGRESSION ANALYSES

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In the analyses of the program schedule data, we made use of results from two secondary regression equations. The first was used to estimate the time from long-lead release to the first delivery for production lots where data for the interval were not available. The estimates are used in developing metrics for concurrency. The purpose of the second regression equation was to produce estimates of cumulative average procurement cost for the first 1,000 missiles for all programs. The estimates were, in turn, used as an instrument for average missile costs in the regression estimating the total number of EMD missile launches.

TIME FROM LONG-LEAD RELEASE TO FIRST DELIVERY

The data used to develop an estimating relationship for the interval were drawn from those programs for which data for both long lead and full-funding release were available. In all there are twenty observations. The resulting regression estimates the number of months from long-lead release to first production delivery (LL to 1st Delivery) based on the number of months from full-funding release to first production delivery (FF to 1st Delivery):

$$\text{LL to 1st Delivery} = 14.37 + \underset{(.01)}{.59}\ (\text{LL to 1st Delivery})$$

$N = 20$ $R^2 = .58$ Adjusted $R^2 = .72$ $\hat{\sigma} = 2.69$

Table D-1 presents the data used and the regression errors. Figure D-1 plots number of months from long-lead release to first production delivery predicted by the above equation against program actuals.

Table D-1. Data and Prediction Error Summary for Long-Lead Release to First Production Regression

Program	Production Lot	FF to 1st Delivery (months)	LL to 1st Delivery (months)	Predicted LL to 1st Delivery (months)	Error (Actual-Pred.)
Sparrow F	FY68 Pilot Production	13	28	22.0	6.0
Phoenix A	FY72 Production	15	27	23.2	3.8
Phoenix C	FY80 Production	33	35	33.8	1.2
Phoenix C	FY81 Production	21	25	26.8	-1.8
Phoenix C	FY82 Production	20	24	26.2	-2.2
AMRAAM	FY86 Production	11	22	20.9	1.1
AMRAAM	FY88 Production	13	20	22.0	-2.0
AMRAAM	FY89 Production	13	22	22.0	0.0
Maverick IIR	FY82 Production	13	18	22.0	-4.0
Maverick IIR	FY84 Production	16	28	23.8	4.2
SRAM	FY71 Production	14	21	22.6	-1.6
Harpoon	Pilot Production	13	19	22.0	-3.0
Harpoon	First Production	12	20	21.5	-1.5
ALCM	FY80 Production	20	25	26.2	-1.2
HARM	First Production	12	23	21.5	1.5
Hellfire	FY82 Production	19	26	25.6	0.4
PATRIOT	FY80 Production	16	26	23.8	2.2
PATRIOT	FY81 Production	23	29	27.9	1.0
PATRIOT	FY82 Production	16	22	23.8	-1.8
Stinger	Low Rate Production	20	24	26.2	-2.2

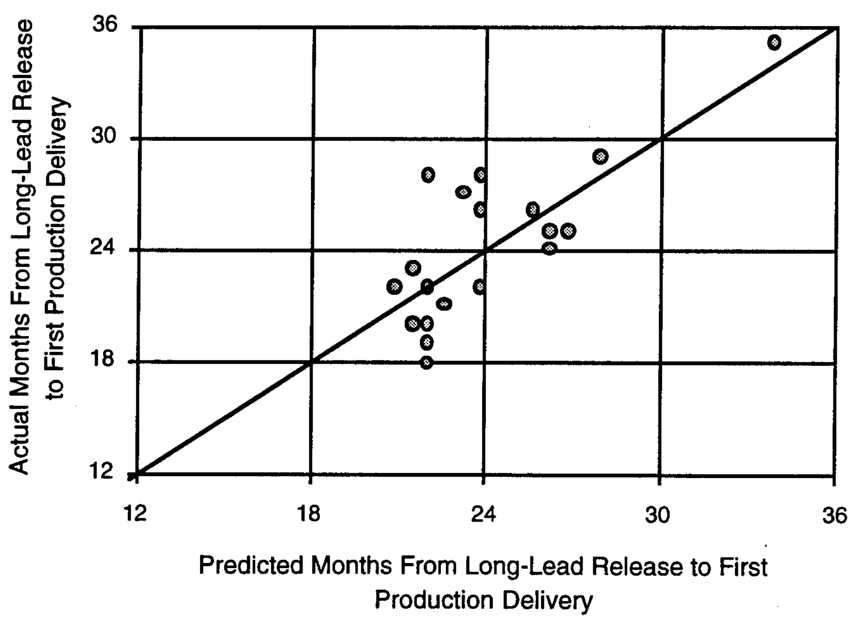

Figure D-1. Predicted Versus Actual Time From Long-Lead Release to First Production Delivery

AVERAGE PROCUREMENT COST FOR MISSILE PROGRAMS

We estimated a cost-estimating relationship for the procurement cumulative average cost (CAC) of missile programs, normalized to a buy of 1,000 units (CAC_{1000}). Data were collected at the budget/Selected Acquisition Report (SAR) level. CAC_{1000} is expressed in thousands of FY90 dollars. Costs include all procurement costs including support investment and initial spares. Independent variables used in the regression include the maximum range of the missile in nautical miles (nmi.) and a dummy variable, IR/Active Radar, taking on the value of one if the missile had infrared or active radar guidance and zero otherwise. The resulting regression is presented below.

$$CAC_{1000} = 50.826\ (\text{Maximum Range})^{.679}\ 2.091^{(\text{IR/Active Radar Dummy})}$$

(.01) (.01)

$N = 17$ $R^2 = .99$ Adjusted $R^2 = .99$ $\hat{\sigma} = .254$ $\hat{\sigma}' = 260.1$ Intercept adjustment = 1.033

Table D-2 presents the data used and the regression errors. Because our EMD missile launch database contains programs not included in the procurement cost regression, values for the missing programs were estimated using the CER and available technical parameters; estimates for these programs are also included in Table D-2.

Table D-2. Data and Prediction Summary for Procurement Cost Regression

	Maximum Range (nmi)	IR/Active Dummy	CAC_{1000} (Thousands of FY90 dollars)	Predicted CAC_{1000}	Error (Actual-Pred.)	Multiplicative Error (Actual/Pred.)
IHAWK	21.6	0	—	410	—	—
PATRIOT	86.3	0	—	1,049	—	—
SM-2	69.6	0	1,329	907	422	1.47
Stinger	1.6	1	176	146	29	1.20
Sprint	32.0	0	—	535	—	—
Spartan	400.0	0	—	2,973	—	—
Sparrow F	24.0	0	522	440	82	1.19
Sparrow M	24.0	0	360	440	-80	0.82
Sidewinder L	2.0	1	168	170	-3	0.98
Sidewinder M	2.0	1	163	170	-7	0.96
Phoenix A	72.5	1	1,627	1,949	-322	0.83
Phoenix C	80.0	1	1,710	2,083	-373	0.82
AMRAAM	40.0	1	1,600	1,301	299	1.23
Maverick EO	13.0	0	151	290	-139	0.52
Maverick IIR	13.0	1	552	607	-54	0.91
SRAM	105.0	0	—	1,199	—	—
Harpoon	60.0	1	1,524	1,714	-190	0.89
ALCM	1,500.0	0	6,897	7,294	-397	0.95
HARM	40.0	0	757	622	135	1.22
Hellfire	6.0	0	196	172	24	1.14
Tomahawk	1,350.0	0	6,358	6,791	-433	0.94
TOW-II	2.0	0	67	81	-14	0.82

Figure D-2 plots predicted and actual average procurement costs.

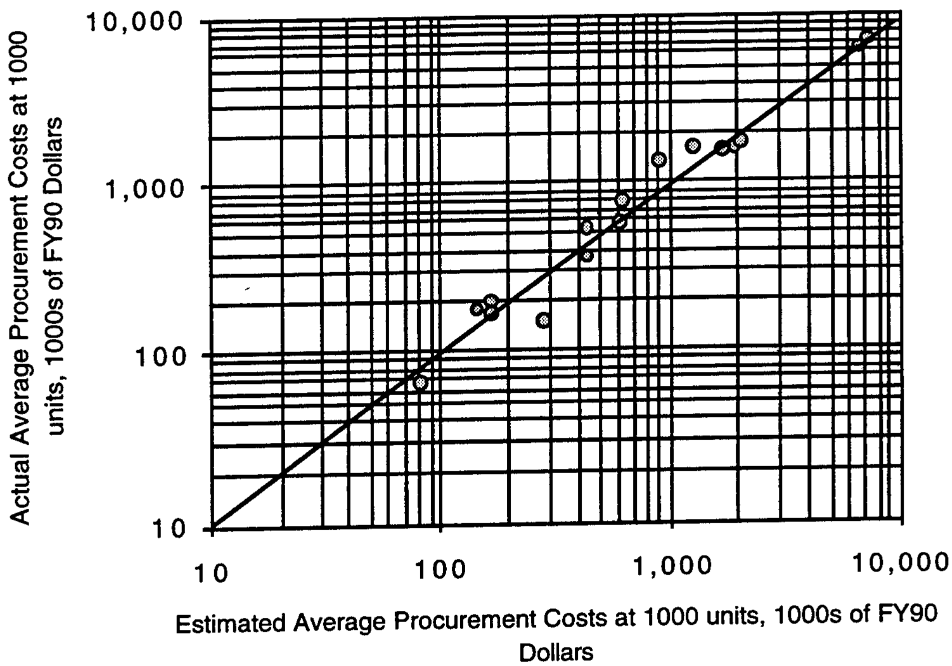

Figure D-2. Predicted Versus Actual Average Procurement Costs

APPENDIX E

FRONTIER FUNCTION TERS

APPENDIX E

FRONTIER FUNCTION TERs

This appendix presents alternative time-estimating relationships (TERs) estimated using a frontier function approach. In this approach, the parameter estimates are determined by a mathematical programming problem where the absolute errors are minimized subject to the constraint that all of the errors lie on or above the regression line. The TER in this case represents the "best" that can be achieved for an interval given the values associated with the independent variables.

APPROACH

Frontier functions are prominent in the production and cost function literature in economics and operations research [55]. In economic theory, production functions (or the cost functions derived from them) represent a technologically defined maximum output (or minimum cost, holding input prices constant). Given that all firms may not be efficient, a least squares fit of observed inputs on outputs will not yield unbiased estimates of an economic production function. Many alternative estimation methods have been proposed. The method of most interest to us employs non-linear programming to estimate a technological frontier. Here, the objective function is the sum of absolute errors, which is minimized subject to the constraint that all of the errors are above (lower-bounded cost function) or below (upper-bounded production function) the frontier. The decision variables are the parameter estimates. If the errors can be characterized by some bounded distribution (e.g., exponential or gamma) this becomes a problem of maximum likelihood estimation.

We can think of TERs in the same way as economists think of production functions. For any schedule interval (output) there may be some technologically determined lower bound for a given set of program and missile characteristics (input). Employing the method outlined above, we estimated frontier TERs using the same data as used to estimate the least-squares regression models. An efficiency measure can be derived for each observational unit, where the metric is the time predicted by the frontier function divided by the actual time required. This yields a value of one for the programs on the frontier and values of between zero and one for the others.

By specifying a distribution for the errors and estimating the parameters for that distribution we accomplished two important goals. First, we were able to perform hypothesis tests on the parameter estimates by individually imposing the null hypotheses as restrictions on the parameters and employing likelihood-ratio tests. Secondly, defining the distribution above the frontier will allow analysts examining program plans to make probability statements about planned schedule intervals.

The answer to the question of which of the models (least squares or frontier) is most appropriate depends on at least two criteria. The first is an objective criteria about the distribution of model errors. If the distributional assumptions associated with the least squares fit appear to be violated (confirmed) and those associated with the frontier function appear to be confirmed (violated) then the frontier (least-squares) function should be applied. The second criterion is more subjective. The question is: what is the analyst's intuition about the nature of the schedule interval being examined? Is their some positive bound on the interval being examined below which the probability of occurrence is zero?

In estimating frontier functions for the first guided-launch TER, we found that the exponential distribution was best suited to modeling its error structure. The probability density function for the exponential distribution is defined as:

$$\text{if } t \geq 0, f(t) = \lambda e^{-\lambda t}, \text{ otherwise } f(t) = 0,$$

where, in our case, t is the number of months the observation falls above the frontier. The exponential distribution meets the frontier-function requirement that all of the errors must be greater than or equal to zero. It is also intuitively appealing in this application because it has long been applied to queuing, reliability, and other types of duration models. We examined more flexible distributions such as beta, gamma, and Weibull and found little or no advantage to using them to characterize the statistical properties of the frontier function.[1] The need to give-up degrees of freedom to estimate the multiple parameters of the alternatives, in contrast to the computational simplicity associated with the exponential distribution led us to apply it to all of the frontier function problems.

Given the exponential probability density function and the general form of the frontier function, ax^b, we can form the log-likelihood function,

---

1 The method in making this judgment was the comparison of empirical and theoretical cumulative density functions for the alternative models.

$$ln\ L = \sum_i ln[\lambda e^{-\lambda(Y_i - a x_i^b)}],$$

where Y_i and x_i are data and λ, a, and b are the parameters to be estimated. Maximum likelihood estimates of the parameters were derived by maximizing $ln\ L$. The function has the convenient property that it can be maximized in a two-stage process. The parameters a and b are first estimated using the nonlinear programming scheme outlined above. This provides values of t for all observations. The maximum likelihood estimator of λ can then be calculated as $1/\bar{t}$, where $\bar{t}$ is the analogy estimator for expected value of t, $\hat{\mu}$. Hypothesis tests on the parameter estimates can be made by maximizing restricted and unrestricted likelihood functions and employing the likelihood ratio test.

In our analyses of the various schedule intervals using the frontier function approach, we found acceptable results only in the case of the time to first guided launch (TFGL) schedule interval. For the other intervals, results showed non-significant or counter-intuitive parameter estimates. This indicates that the other intervals are best characterized using the conventional least-squares approach.

TIME TO FIRST GUIDED LAUNCH

The resulting frontier function for the baseline model is presented below. Also presented are measures of statistical significance and other model attributes.

$$TFGL = 4.835\ (\text{Guidance Weight})^{.280}\ 1.787^{(\text{Interceptor})}\ .731^{(\text{Mod})}$$
$$(.01)\quad (.01)\quad (.01)$$
$$N = 28 \qquad \lambda = .216 \qquad \hat{\sigma}^2 = 21.44 \qquad \hat{\sigma} = 4.63$$

Except for the intercept, parameter estimates change only slightly from the least-squares result. The TER will yield the expected value of the interval if $\hat{\mu}$ is added to the frontier function estimate. The statistic $\hat{\sigma}^2$ is calculated as $1/\lambda^2$. The standard error of the estimate is $\hat{\sigma} = \hat{\mu}$. We can compare the $\hat{\sigma}$ (4.6 months) for the frontier function with $\hat{\sigma}'$ for the transformed least-squares model (4.7 months). Figure E-1 plots time to first guided launch predicted by the baseline frontier function against program actuals. Figure E-2 presents empirical and exponential cumulative density functions for the baseline frontier function.

For the baseline TER, the exponential distribution does a good job at characterizing the errors above the frontier function. Table E-1 summarizes the prediction errors associated with the baseline frontier function.

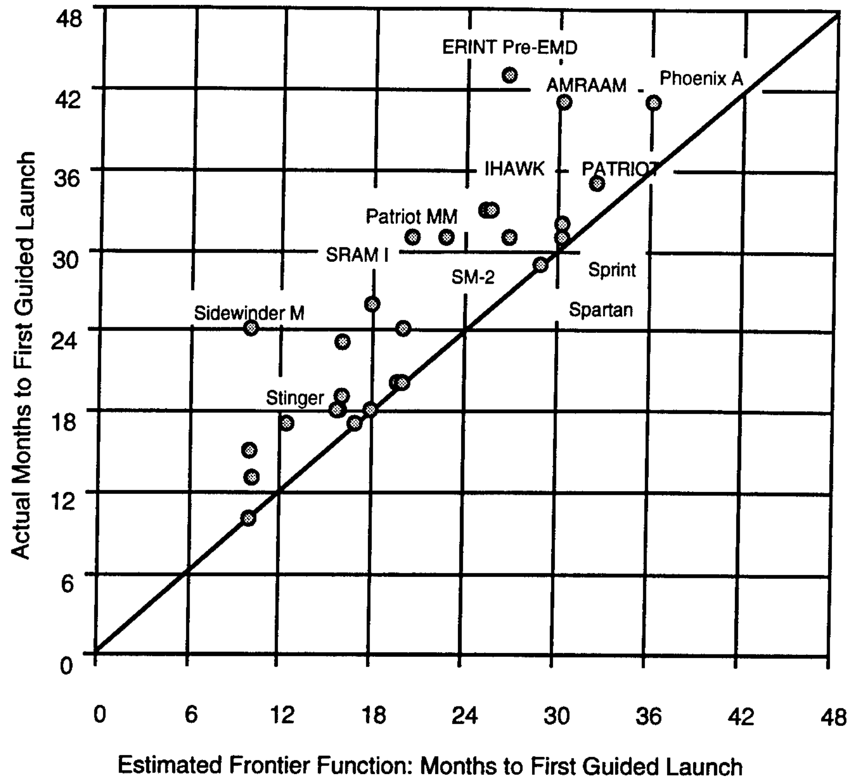

Figure E-1. Frontier Versus Actual Time From EMD Start to First Guided Launch: Baseline Model

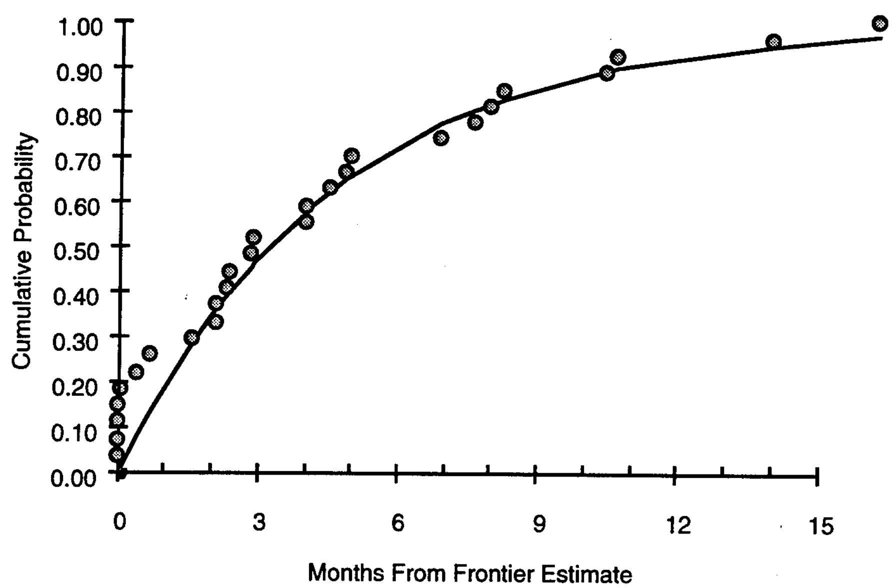

Figure E-2. Empirical Versus Exponential Cumulative Density Function: Baseline Frontier Function TER

Table E-1. Prediction Error Summary: Baseline Frontier Function TER

Program	Actual Value (Months)	Frontier Value (Months)	Error (Actual – Frontier)	Efficiency (Frontier/Actual)
IHAWK	33	25.4	7.6	0.77
PATRIOT	35	32.6	2.4	0.93
SM-2 Blk-1	31	22.8	8.2	0.73
Stinger	17	12.5	4.5	0.73
Sprint	32	30.4	1.6	0.95
Spartan	29	29.0	0.0	1.00
PATRIOT MM	33	25.6	7.4	0.78
ERINT-1	43	26.7	16.3	0.62
Sparrow F	20	19.6	0.4	0.98
Sparrow M Pre-EMD	20	20.0	0.0	1.00
Sparrow F	24	20.0	4.0	0.83
Sidewinder L Pre-EMD	10	10.0	0.0	1.00
Sidewinder L	15	10.0	5.0	0.67
Sidewinder M	24	10.0	14.0	0.42
Phoenix A	41	36.1	4.9	0.88
Phoenix C	31	26.9	4.1	0.87
AMRAAM Pre-EMD	31	30.3	0.7	0.98
AMRAAM	41	30.3	10.7	0.74
Maverick E.O.	17	16.9	0.1	1.00
Maverick IIR Pre-EMD	18	18.0	0.0	1.00
Maverick IIR	26	18.0	8.0	0.69
SRAM	31	20.6	10.4	0.66
Harpoon Pre-EMD	18	15.9	2.1	0.88
Harpoon	18	15.9	2.1	0.88
ALCM	18	15.7	2.3	0.87
HARM Pre-EMD	23	16.1	6.9	0.70
HARM	19	16.1	2.9	0.85
Hellfire	13	10.2	2.8	0.78

We also estimated the augmented TER using the frontier function approach. The resulting frontier function for the augmented model and measures of statistical significance and other model attributes are presented below.

$$\underset{}{\mathrm{TFGL}} = 6.889\ \underset{(.01)}{(\text{Guidance Weight})^{.318}}\ \underset{(.01)}{(\text{Power Density})^{.172}}\ \underset{(.01)}{1.330^{(\text{Interceptor})}}$$

$N = 16$ $\lambda = .217$ $\hat{\sigma}^2 = 21.25$ $\hat{\sigma} = .4.61$

Although the Power Density variable is statistically significant, the results show that nothing is gained by its inclusion in the model in lieu of the MOD dummy variable. Figure E-3 plots time to first guided launch predicted by the augmented frontier function against program actuals. Figure E-4 presents empirical and exponential cumulative density functions for the augmented frontier function.

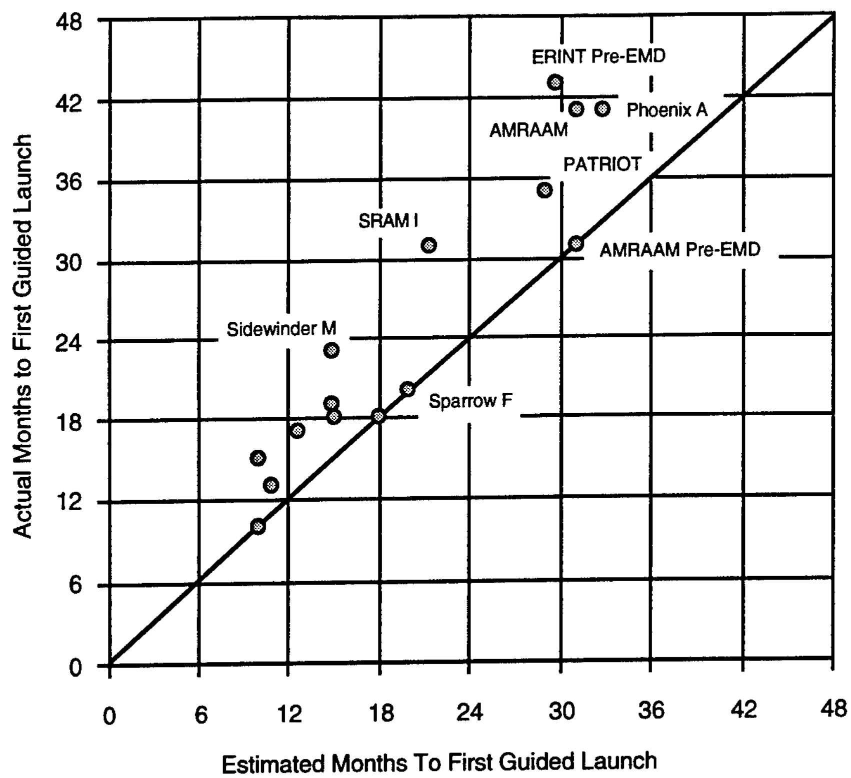

Figure E-3. Frontier Versus Actual Time From EMD Start to First Guided Launch: Augmented Model

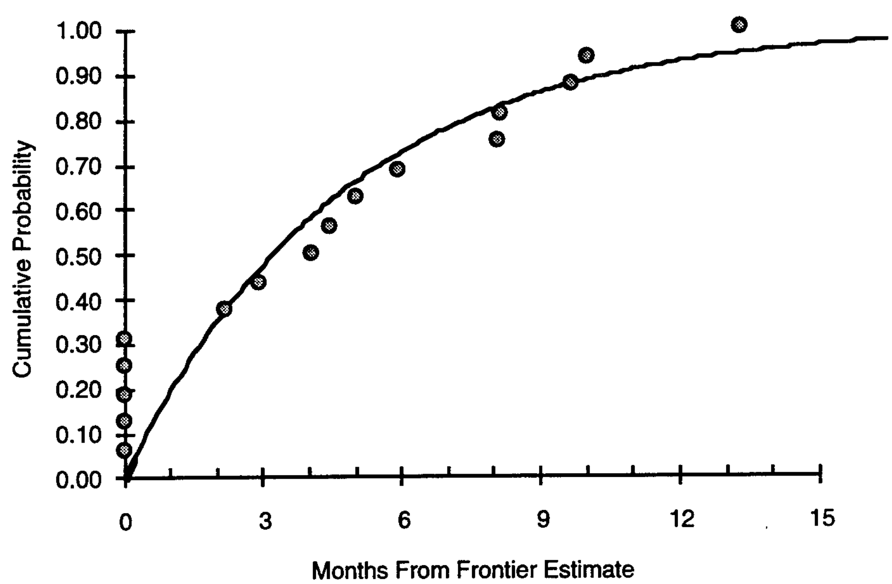

Figure E-4. Empirical Versus Exponential Cumulative Density Function: Augmented Frontier Function TER

The errors from the augmented TER do not follow the exponential distribution as well as those from the baseline TER. Overall we found no advantage associated with the augmented frontier function. Table E-2 summarizes the prediction errors associated with the augmented frontier function.

Table E-2. Prediction Error Summary: Augmented Frontier Function TER

Program	Actual Value (Months)	Frontier Value (Months)	Error (Actual – Frontier)	Efficiency (Frontier/Actual)
PATRIOT	35	29.1	5.9	0.83
Stinger	17	12.5	4.5	0.74
ERINT-1	43	29.7	13.3	0.69
Sparrow F	20	20.0	0.0	1.00
Sidewinder L Pre-EMD	10	10.0	0.0	1.00
Sidewinder L	15	10.0	5.0	0.67
Phoenix A	41	32.9	8.1	0.80
AMRAAM Pre-EMD	31	31.0	0.0	1.00
AMRAAM	41	31.0	10.0	0.76
SRAM	31	21.3	9.7	0.69
Harpoon Pre-EMD	18	18.0	0.0	1.00
Harpoon	18	18.0	0.0	1.00
ALCM	18	15.1	2.9	0.84
HARM Pre-EMD	23	14.9	8.1	0.65
HARM	19	14.9	4.1	0.79
Hellfire	13	10.8	2.2	0.83

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ABBREVIATIONS

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A	Aegis
ABM	anti-ballistic missile
AD	Advanced Development
ALCM	Air-Launched Cruise Missile
AMRAAM	Advanced Medium-Range Air-to-Air Missile
BMDO	Ballistic Missile Defense Organization
Cat	Category
CD	Concept Definition
CDR	Critical Design Review
CDT	contractor demonstration test
CER	cost-estimating relationship
CTE	contractor test and evaluation
CTF	Controlled Test Flight
CTV	controlled test vehicle
db	decibel
DPG	Dugway Proving Ground
DSARC	Defense Systems Acquisition Review Council
DT	development testing
DT&E	development test and evaluation
EAFB	Eglin Air Force Base
ECCM	electronic counter-countermeasures
ECS	Engagement Control Station
EDM	engineering development model
EDT	Engineering Development Testing
EMD	engineering and manufacturing development
EO	electro-optical
ER	extended range
ERINT	Extended Range Interceptor
ET	engineering test
FLAGE	Flexible Light-Weight Guided Experiment
FTR	flight test round

GD	General Dynamics
GHz	gigahertz
GM	guided missile
GTF	Guided Test Flight
GTV	guided test vehicle
HAFB	Holloman Air Force Base
HARM	High-Speed Anti-Radiation Missile
HAST	high-altitude supersonic target
ICBM	intercontinental ballistic missile
ICC	information control center
ICWAR	improved continuous wave acquisition radar
IFF	identification, friend or foe
IHPI	improved high-power illuminator
IIR	imaging infrared
IOC	initial operational capability
IOT&E	initial operational test and evaluation
IOTE	Initial Operational Test and Evaluation
IP	initial production
IPS	Improved Propulsion System
IPT	Initial Production Test
IR	infrared
JTE	joint test and evaluation
km	kilometer
MAFB	McConnell Air Force Base
MDAG	Modular Digital Airborne Guidance
MICOM	Missile Command
MM	multi-mode
MMS	multimode seeker
MR	medium range
MSE	multiple shot engagement
MSR	Missile Site Radar
NAWC-WD	Naval Air Warfare Center, Weapons Division
NTE	Navy technical evaluation
NWC	Naval Weapons Center

OLS	ordinary least squares
OPEVAL	operational evaluation
OT	operational testing
PAC	Patriot Advance Capability
PAR	pulse acquisition radar or Perimeter Acquisition Radar
PD	performance demonstration
PDT	Performance Demonstration Test
PMTC	Pacific Missile Test Center
POP	proof of principle
POST	passive optical seeker technique
PPT	Production Prototype Testing
PQT	prototype qualification test
R&D	research and development
RAG	Regular Airborne Guidance
RCS	radar cross-section
RDT&E	research, development, test and evaluation
RMP	reprogrammable microprocessor
ROR	range only radar
RTP	released to production
RV	reentry vehicle
SAR	Selected Acquisitions Report
SAT	separation and test
SCAD	subsonic-cruise armed decoy
SECDEF	Secretary of Defense
SLBM	submarine-launched ballistic missile
SLCM	sea-launched cruise missile
SM	Standard missile
SRAM	Short-Range Attack Missile
SRHIT	Small Radar Homing Interceptor Technology
TBM	tactical ballistic missile
TECHEVAL	technical evaluation
TER	time-estimating relationship
TMD	tactical missile defense
TP	test prototype
TVM	track-via-missile
UTTR	Utah Training and Test Range

VE	value engineering
WSMR	White Sands Missile Range

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The research documented in this report was initiated to provide representatives of the Ballistic Missile Defense Organization (BMDO) with methods for assessing the reasonableness of proposed acquisition schedules for surface-based interceptor elements of proposed missile defense architectures. Such methods should reproduce schedules typical of analogous historic systems while accounting for schedule variations associated with differing technical or program characteristics. IDA collected historical schedule and technical data on 22 surface-launched interceptor programs and other relevant missile programs. Historical missile acquisition program schedules and related data are presented in consistent formats for use in data analyses and for comparison with proposed acquisition programs. We performed statistical analyses on schedule intervals in the data to derive time-estimating relationships (TERs). The TERs were integrated into a schedule-assessment tool that spans the period from the start of pre-engineering and manufacturing development prototype efforts through early production. In applying statistical analyses, we treated schedule intervals (measured in months) as dependent variables and regressed them against independent variables that were thought to influence these intervals. We used both conventional least-squares regression as well a more novel frontier function approach.

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